<u>THE RELATIONSHIP BETWEEN INSPECTION TIME AND IQ</u>

<u>IN SPECIFIC READING DISABLED GRADE 7 STUDENTS</u>

THE RELATIONSHIP BETWEEN INSPECTION TIME AND IQ IN SPECIFIC READING DISABLED GRADE 7 STUDENTS

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This thesis contains no material which has been accepted for the award of any degree or diploma in any university, nor any material previously published or written by another person, except when due reference to such material is made in the text.

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ABSTRACT

This study investigated the relationship between inspection time and IQ in a total sample of 155 specific reading disabled (SRD) and normal children aged 12 and 13 of average and above-average intelligence and in IQ matched subsamples of 24 each. The Standard Progressive Matrices and a computerised inspection time (IT) task using the adaptive staircase procedure with an accuracy level of 79.4% were adopted. It was hypothesised that, due to the low level perceptual deficits involved in specific reading disability, there would be a significant difference between the mean ITs of SRDs and normals, which in turn would lead to less correlation between IT and IQ in SRDs, thereby implicating these low level visual deficits in the association between IT and IQ. The results showed that there was no significant difference between the mean ITs of both groups, nor was there a differential IT-IQ correlation in the predicted direction. On the contrary, a marginally significant higher IT-IQ correlation was found in SRDs. This presents a theoretical paradox, for whereas the former results indicate that low level perceptual deficits are not involved in inspection time, the latter finding suggests that they are. Further research is needed to resolve this anomaly.

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CHAPTER 1

INSPECTION TIME

1.1 THE CONSTRUCT

Inspection time has been heralded both as a promising tool for the study of intelligence (Jensen, 1982) and a "culture-fair" measure of individual differences in intellectual functioning (Brand & Deary, 1982) and, as such, has generated a great deal of research in the past decade.

First proposed by Vickers, Nettelbeck and Willson (1972), inspection time is defined as the time required by an individual to make a single observation or "inspection" of the sensory input on which a discrimination of relative magnitude is based. The construct is derived from the accumulator model of sensory sampling formulated by Vickers (1970; 1979).

1.1.1 Rationale

The accumulator model is a model of comparative judgement which was suggested initially to explain the fact that, even when two stimuli are identical or very difficult to discriminate, individuals do not continue to take observations indefinitely, but reach a decision in a time which is comparable to that for a discrimination of moderate difficulty. The model, therefore, assumes that following sensory registration (in a two-choice discrimination task) the individual collects or "accumulates" information favouring either decision in two separate short term memory stores or "accumulators" which act as counters, each with its own critical magnitude. As soon as one of these accumulators reaches its predetermined criterion level, the decision can be made. In this way, the accumulating totals operate as two complementary, unidirectional random walks; a step in one direction is taken only if a positive observation is encountered, and a step in the other is made if the observation is negative (Vickers, 1979). The model further assumes that the evidence builds up at a steady rate from a number of discrete information samples or inspections each taking a small, constant period of time and contributing a variable amount of information.

This process occurs against a background of internal and external noise due to the sensitivity of the individual and the physical variability of the stimulus, respectively. It is also influenced by the individual's decision bias and the strategy he/she adopts with regard to the speed-accuracy trade off. In an optional stopping model, as is the accumulator model, the individual sets his/her own criterion levels, and these reflect his/her degree of caution in making a response. Therefore, if the individual shows a preferential bias towards a particular decision, he/she can adopt a lower criterion for that response, and be prepared to make it on the basis of less evidence. In the same way, he/she can choose to reach a decision faster by lowering his/her decision criteria, or to aim for a more accurate decision by raising these values. Consequently, the total time taken to make a discrimination depends largely on the level of caution adopted by the individual, that is the number of inspections taken; and the time required for each, that is the inspection time. This can be expressed in the following equation (Nettelbeck, in press) originally suggested by Vickers (1970): $L = (N \times IT) + t$,

where L = response latency

N = total number of inspections made to reach a decision

IT = time required to take a single observation

t = residual nondecision time associated with sensory delay and motor performance.

According to this formulation, inspection time could be measured in a task that needed only a single inspection, as long as that observation favoured the correct response and was equal to or exceeded the response criterion, and t was eliminated.

1.1.2 Procedure

Such a task was devised by Vickers et al (1972) based on the original two-line discrimination task used by Vickers (1970) to test the accumulator model. The stimulus consisted of two vertical parallel lines of different lengths, and the subject's task was to determine which line was shorter, responding with a key press on the left or the right. The lines were viewed from a distance of 66 cm so that the stimulus difference of 9.6 mm corresponded to a visual angle of 0.8 °. This value was 2.67 times 0.3 °, their provisional upper estimate for the level of noise in the human visual system, based on available data from an elderly population sample. The investigators reasoned that this task should result in virtually error-free performance, since the expected probability of making an error was .005, provided the observer had the opportunity to make one inspection of the sensory input. However, allowing for the possibility of other sources of error, such as anticipatory responses or momentary fluctuations in attention, the more conservative 97.5% limit of confidence was accepted. By randomly varying the presentation time of the discriminanda, it was thought that it would be possible to estimate inspection time by the minimum target stimulus duration necessary for error-free performance at this predetermined level of accuracy, independently from the time taken to register a response. (The estimate of inspection time at this 97.5% limit of confidence is designated by the symbol λ). Thereby, the effects of t, in the above equation, should be eradicated, and problems related to motivation and degree of caution associated with reaction time (RT) measures avoided.

Exposure durations were controlled by a backward mask in which the two lines to be discriminated were overwritten by two longer lines of equal length. An extremely brief presentation of a visual stimulus that does not allow the individual to retain any vivid image of the stimulus presentation in memory, would mean that any discrimination of the presented discriminanda would be based chiefly on immediate input. Not only would the input be curtailed by the mask, but also any further <u>processing</u> of that input, over and above the interval between target onset and mask onset, that is, the stimulus-onset-asynchrony (SOA).

Thus, as far as possible, this proposed task should satisfy the conditions required to measure inspection time.

The subsequent experiments of Vickers and his colleagues (1972) confirmed their assumptions. Ten undergraduates were tested on this procedure in two experiments and the two group means turned out to be very close (105 and 99 msec) as were the distributions of λ for individual observers which were highly correlated (Pearson $r = .8$). The data therefore suggested that 100 msec is a good estimate of the average time needed to make one momentary inspection of sensory input. This is supported by Vickers (1970) mean estimate of λ from the difference between minimum and modal RT. Estimates of noise ranged from 0.27 ° of visual angle up to 0.45 °, with a mean of 0.32 °, which is higher than in previous experiments but within the expected order. Further comparisons of λ with estimates of L (overall response latency) showed no evidence of any correlation, suggesting that λ is a stable, independent and reliable index of individual differences in perceptual performance.

Thus, Vickers and his coworkers produced a discrimination task with such minimal cognitive content that a decision could be made on the basis of one inspection. Since then a variety of stimuli have been developed in different modalities: visual, auditory, and tactile, requiring different modes of presentation and forms of response. These have included names and pictures of animals (Hartnoll, 1978, cited in Brand 1981), lens-topped neon bulbs (Nettelbeck, 1982; Nettelbeck & Kirby, 1983a,b), alphanumeric characters (Irwin, 1984; Longstreth, Walsh, Alcorn, Szeszulski & Manis, 1986), red and blue vertical lines (Hosie, 1979, cited in Brand, 1981), white horizontal lines (Mackenzie & Bingham, 1985; Mackenzie & Cumming, 1986), squares and diamonds (Turner, 1986), tones (Deary, 1980, cited in Brand & Deary, 1982; Irwin, 1984), and finger vibrators (Nettelbeck & Kirby, 1983a).

Nevertheless, despite the variation of specific dicriminanda across studies, the estimation of the minimum possible amount of time to maintain accuracy is central to all inspection time tasks.

1.1.3 Measurement

The estimation of this measure is achieved by either of two basic psychophysical procedures: the method of constant stimuli or the method of limits. In the method of constant stimuli a fixed number of trials are required at each of several specific exposure durations which are selected from a wide range, so as to include the expected measure of inspection time, and then presented, generally, in randomised order (Nettelbeck, 1985). The target stimulus duration at which the individual reliably makes the specified number of correct responses is therefore the estimate of inspection time.

The method of limits, on the other hand, is an adaptive staircase procedure, whereby stimulus exposure duration is lowered or raised according to the individual's performance in terms of the specified accuracy level, until the final critical duration at which this criterion is reflected is established empirically (Nettelbeck, 1982). Several versions of the adaptive method have been utilised including the Parameter Estimation by Sequential Testing (PEST), developed by Taylor and Creelman (1967, cited in Nettelbeck, in press) and favoured by Nettelbeck in Adelaide, and the sequential estimation of points on a psychometric function by Wetherill and Levitt (1965), preferred by Mackenzie in Tasmania.

In the early studies on inspection time, the method of constant stimuli was used but since 1982 the method of limits has been more popular due partly to the introduction of computers for stimulus presentation, but mainly to the relative advantages and disadvantages of the two methods. The adaptive method has the distinct advantage of being more efficient in its use of trials than the method of constant stimuli, since most judgements are made at exposure durations close to the target level. This procedure also controls for individual differences in the amount of practice undertaken to reach the specified level of accuracy, which is an important consideration in the comparison of different age and ability groups. However, according to Nettelbeck (1985), there are two minor disadvantages with the sequential estimation procedure, both related to measurement accuracy. Firstly, RT for any particular exposure duration cannot be measured as reliably as by the alternative method, because the number of trials at different SOA's are not balanced and will be small at exposures well above the target level. Secondly, despite strong test-retest correlations, absolute levels of individual estimates can fluctuate more widely than has been found with the method of constant stimuli. This is due to the fact that inspection time is extrapolated on the basis of only one threshold measure, making the adaptive method more sensitive to occasional lapses in attention.

The procedure of extrapolating inspection time from a lower level of response accuracy to the 97.5% level has been adopted by Nettelbeck and his colleagues, because direct measurement at the 97.5% confidence limit with high reliability under either the method of constant stimuli or the method of limits would demand a great number of trials. This technique is deemed necessary only by those who adhere to the original Vickers (Vickers et al, 1972) model whereby the concept of inspection time is defined in terms of the 97.5% threshold (λ). Other researchers, like Mackenzie and his co-workers (Mackenzie & Bingham, 1985; Mackenzie & Cumming, 1986), consider that extrapolation is unnecessary on the grounds that it is a linear transformation and rather than increase the accuracy, may, owing to the possibility of unpredictable trends, provide a less accurate description of a subject's performance than the initially calculated value. Therefore, although the construct λ provides a somewhat "standard" description of what inspection time may measure, the estimate of λ has no particular advantage over other estimates more directly calculable from subjects' responses within an experiment.

In this way, the construct of inspection time originated and developed within an information processing framework. However, with the reported finding of Nettlebeck and Lally (1976) that there was a significant negative correlation between IT and several performance subtests in the WAIS, a new direction was taken by this research. The nature of the relationship between IT and intelligence became a subject for debate and triggered a proliferation of hypotheses. The ensuing research mainly focused on assessing the size of the relationship, establishing the reliability of the measure, and determining its significance with regard to current theories of intelligence and information processing models. This growing body of research will be discussed in the following sections.

1.2 MENTAL SPEED

The intuitive notion that a relationship exists between intelligence and some kind of mental speed has prevailed in psychology since Galton (1883) first conceived the radical idea of measuring the characteristics of intelligence. Favouring a unitary concept of intelligence as general ability, Galton conceived of it as largely innate and, therefore, took a biological approach to its measurement. His "mental tests" consisted of simple measures of physiological functions, such as visual and auditory acuity measures and reaction times. These simple measures were later extended and systematised by Cattell (1890) in America, but, although a considerable amount of research was generated by the concept of mental speed (Beck, 1933; McFarland, 1928), many of the studies were too indefinite and general to provide evidence either for or against the idea.

One oft-quoted study in favour of an association between speed and general ability is that of Peak and Boring (1926). Using a simple reaction time paradigm with 5 subjects, their study produced remarkable results, achieving correlations of .7 and .9 between the Alpha and Otis Tests and reaction times, respectively. Peak and Boring, therefore, concluded "that speed of reaction is an important, and probably the most important, factor in individual differences in the intelligent act" (1926, p.92). However, this was one experiment among a number of earlier unsuccessful ones with more prestige (Sharp, 1898/99; Wissler, 1901, cited in Deary, 1986).

Interest in the speed-intelligence hypothesis declined due partly to the lack of substantial evidence to support it, and partly to the emergence of behaviourism, with its essential belief in the overriding impact of environmental influence on intellectual ability. There was a consequent swing away from biological measures to a search for new measures of intelligence in the areas of everyday life and education (Eysenck, 1986b).

Among the first to explore such measures was Binet, who favouring an environmentalist view, saw intelligence as a kind of conglomerate of various separate abilities (Eysenck, 1986b,c). Contrary to Galton, he considered that the best test of intelligence would be a method of problem solving in everyday life situations, which would inevitably involve a good deal of cultural specificity and learning. He argued that it was necessary to attend directly to the cognitive faculties of intrinsic interest, rather than to assume that they would be indexed by the simpler functions. Binet's views and his methods of constructing test items had considerable influence on the measurement of intelligence, as can be seen from our present-day tests of intelligence, which are all IQ tests of the Binet type. What counted was that the tests worked. Not only did they correlate with one another, but they also served to differentiate older children from younger ones and those judged more clever from those independently judged less able (Mackintosh, 1981).

Nevertheless, the concept of mental speed did not entirely disappear. It was retained in the early influential theories of intelligence like that of Thorndike (1926), who advanced the suggestion that human abilities should be measured in three respects: (i) height or level of difficulty, (ii) extent or range of different tasks, and (iii) speed. Furthermore, with the notable exception of the Binet scales, most intelligence and aptitude tests have incorporated an element of timed performance within them. Faster performance is judged to be quantitatively superior to slower performance, provided that a high level of accuracy is maintained. This may be argued with some empirical justification (Elliot & Murray, 1977; Kaufman, 1979).

The psychometric paradigm continued as the primary means for studying intelligence until the early 1950's witnessed its decline and the ascendancy of the information processing paradigm (Sternberg, 1981). Two important studies from opposite sides of the Atlantic brought the speed-intelligence hypothesis clearly under review. Hick (1952) and Hyman (1953), using the principles of information theory, independently demonstrated that response speed increases linearly with increasing number of "bits" of information, that is as a function of $\log_2$ of the number of choices or stimulus/response alternatives.

If intelligence is conceived of as speed of information processing, it may be hypothesised from the Hick-Hyman law that simple reaction time, involving zero "bits" of information, should not correlate with intelligence, but the slope of the regression line, showing increase of reaction time with amount of information processed, should correlate negatively with intelligence (Eysenck, 1967). In other words intelligent subjects would show less increase in reaction time with increase in the number of choices than would dull ones. This prediction was tested by Roth (1964, cited in Jensen, 1982), who demonstrated that while, as expected, simple reaction time was independent of IQ, speed of information processing (the slope) correlated significantly with IQ, in the predicted direction.

Past rejection of the mental speed concept on the grounds that simple reaction time failed to correlate with IQ was shown to be invalid by these findings. On the contrary, reaction time experiments, properly interpreted, do not appear to contradict a theory of intellectual functioning based on the notion of mental speed.

Such a theory was proposed by Furneaux (1960) who suggested that the major cognitive determinant of intellectual differences was mental speed, but that, in addition, two non-cognitive personality factors, namely continuance (persistence in problem solving in the face of task difficulty) and error checking (to avoid impulsive incorrect solutions) were also involved. Subsequently, Eysenck (1967) incorporated some of these components into his three-dimensional model of intelligence, introducing a new dimension termed "quality" which was made up of mental speed and power. These he saw as the fundamental aspects of all mental activity, although they were qualified to some extent by the other two dimensions, that is the mental processes involved and the test materials used. The main source of variance was mental speed.

Thus, interest in the Galtonian approach to intelligence was revived, and the number of studies aimed at finding direct psychophysical techniques to evaluate the concept of mental speed and its influence on intellectual ability increased. Several researchers have demonstrated that a positive relationship exists between the speed with which individuals can process information and the scores they obtain on a variety of intelligence tests. Vernon (1983) suggests that one way to view this relationship is to consider that the speed of processing indices are measuring the efficiency with which people can perform very basic, cognitive operations which underlie other kinds of cognitive and intellectual behaviour. The quality of intellectual activity is therefore ultimately determined by innate neural efficiency.

Three main experimental paradigms or research measures have been designed to assess this level of processing (Eysenck, 1986a,b,c).These are average evoked potentials (AEPs) on an electroencephalogram, reaction time (including simple and choice reaction time), and inspection time (IT).

The AEP technique involves presenting a subject with a repetitive stimulus such as an auditory tone, while recording the electroencephalographic (EEG) signal at the same time. The resulting waveforms, according to Hendrickson (1982a), depict the activity of successive "pulse trains" as information is processed by the brain, providing a fairly direct measurement of the amount of error in pulse train transmission. Various methods have been used to measure these waveforms, such as counting the peaks and troughs or measuring the amount of string obtained by tracing the lines of each waveform. From a series of computer simulation studies, Hendrickson showed that error is cumulative. Also observations of AEP records from other studies have shown that waveforms of low IQ people become smoother as they continue and the circumferences of the waveform envelopes become shorter. Thus low IQ people have shorter waveform "strings" than high IQ people. In a study to test the possibility of using the EEG string method as a measure of intelligence (Hendrickson (1982b) found a high correlation of .72 between the string measure and the full WAIS IQ, for a sample of 219 15 year-olds.

The Hendricksons (1982a,b) interpreted these findings as offering evidence that people with higher IQs process information via a similar process and mechanism as those with lower IQs, but with a greater level of neural accuracy. It is this accuracy in information processing that leads to faster transmission times, when performance is timed. Mackintosh (1986), however, has proposed a different interpretation. He suggests that the high correlation may reflect the stability and uniformity of subjects' responses across trials, which in turn may be attributed to their willingness to comply with instructions or their ability to maintain concentration on a tedious task. He also points out that this correlation has not always been replicated and the past history of failures to replicate in this general area calls for a degree of caution.

Jensen is probably the most prolific and prestigious figure in reaction time studies. He (Jensen, 1981) reports that correlations between IQ and RT in a variety of paradigms though generally fairly low are rarely on the "wrong" side of zero. Most correlations fall in the range 0 to -.5 with a mean in the -.3's. This is true of both simple reaction time (RT) and choice reaction time (CRT), although CRT paradigms give consistently higher correlations, ranging from -.3 to -.5.

From the evidence of all the RT research, Jensen (1981; 1982) concludes that present standard tests of IQ must measure, in part, some fundamental intrinsic aspect of mental ability and not just individual differences in acquired specific knowledge, scholastic skills, and cultural background. He (Jensen, 1982) also considers that an adequate theoretical account of intelligence would more readily be achieved through research on RT, as a simpler information processing phenomenon, than through theorising directly about the more complex phenomenon of intelligence.

However, some doubt has been cast on the accuracy of the various methodologies employed in RT studies and the interpretation of findings (Nettelbeck, 1986; Nettelbeck & Kirby, 1983a).

While the results of the AEP and RT studies are often significant, as Nettelbeck and Kirby (1983a) point out "no single index of timed performance has consistently been correlated strongly with IQ across a wide range" (p.50). The most promising contender is the inspection time measure, under examination in this study. This measure has consistently indicated a negative association and achieved statistical significance in the greater number of studies (with correlations of between -.3 and -.6 for nonretarded populations) and, unlike RT, it is thought to be relatively independent from the influence of motor factors or criterial considerations (Nettelbeck, in press).

There are two schools of thought regarding the nature of what inspection time measures. Brand (1981; Brand & Deary, 1982), on the one hand, views IT as an estimate of mental speed interpreted as the main component of "g" or general intelligence. Brand's model reflects Cattell's (1971) distinction between "fluid" and "crystallised intelligence", in that individuals who can take in information more rapidly at a precognitive early stage of perception, have a greater innate potential to take advantage of future learning experiences. Thus, the ability to take in information rapidly becomes converted into intellectual "power" (Nettelbeck, 1985). Brand distinguishes here between speed of input at the earliest stage of stimulus encoding and the speed of subsequent processes, and he argues that, whereas the former cannot be influenced by conceptual or personality variables, the latter can. It is for this reason that IT reflects processes independent from the influence of cultural experiences that Brand proposes IT as a culture fair test of intelligence.

Further Brand claims that intake speed increases with ontogenetic development, reaching a ceiling around the mental age of 10, and thereby improving and declining in parallel with mental age. He also considers that a relatively high level of intake speed may be a sufficient but not a necessary condition for high levels of IQ, so that some people will have high IQs without correspondingly high rates of information access.

However, according to Nettelbeck (1973), who was involved in the initial design of the inspection time procedure, IT simply measures the rate of sampling of sensory input in the initial stages of information processing. However, in his more recent writings (in press, 1986) Nettelbeck concedes that some kind of mental speed does contribute to intelligence, even though an adequate theory of intelligence cannot be formulated entirely on the basis of mental speed, thereby ruling out the idea of IT as a culture fair test (see also Nettelbeck, 1982; 1983a,b). This modified view was reached on the grounds that (a) IT is a moderately reliable measure of some characteristic which seems to reflect near-optimum performance for many people, and (b) it bears a moderate relationship to IQ, as measured by various tests. He argues (1986) that the results of his studies would support the idea of a mental speed factor which accounts for approximately 25% of the variance in measured intelligence.

1.3 INSPECTION TIME AND MEASURED INTELLIGENCE

Investigation into the strength of the relationship between IT and measured intelligence, first discovered by Nettelbeck and Lally (1976), has generated a number of studies using various procedures, populations, and IQ measures. Nettelbeck and Lally's study, involving a mixed sample of 10 young adults (3 university students and 7 retardates) whose WAIS Full Scale IQs ranged from 119 to 47, produced impressive correlations of -.92 and -.89 between two estimates of IT and Performance IQ. Also the correlations between these IT measures and the various subtests were comparable in size with those indicating the internal consistency of the WAIS. However, the relationship with verbal IQ was not significant with correlations of -.32 and -.41. This association between PIQ and IT was subsequently confirmed by a correlation of -.8 from a larger sample of 48 subjects with PIQs ranging from 57 to 138 (Lally & Nettelbeck, 1977).

In these first two experiments the mean estimate of IT for nonretarded subjects was approximately 100 msec, whereas that for retarded subjects was at least double this figure, being about 200 msec. These measures have held steady for subsequent studies, a result entirely consistent with a close relation between IT and intelligence (Lubin & Fernandez, 1986).

Nettelbeck pursued his research with retarded populations showing that slower perceptual speed among retardates, as revealed by IT measures, is due to a permanent deficiency and not to a slower rate of perceptual development (Nettelbeck & Lally, 1979); that differences in response strategy probably exist between retarded and nonretarded subjects (Lally & Nettelbeck, 1980); and that practice results in slightly improved IT measures for both groups at about the same rate, so that a consistent mean IT difference is maintained between them (Nettelbeck, Evans & Kirby, 1982). Further, Nettelbeck, Cheshire and Lally (1979) tested a possible practical application of IT, that of predicting the performance of retardates on an industrial sewing task. The results indicated that a slow rate of accumulating sensory input was related significantly to errors in the sewing task, particularly as machine speed increased.

Meanwhile, Brand and his associates (Brand, 1981), prompted by the "astonishing" correlations of Nettelbeck's (Nettelbeck & Lally, 1976) original study, carried out five research projects which demonstrated the strength and robustness of the relationship between IT and IQ. The first study (Anderson, 1977, cited in Brand, 1981) replicated the findings of Nettelbeck and Lally (1976) with a correlation of -.88 between IT and IQ as measured on either the Cattell Culture Fair Test or the Stanford Binet across 13 subjects. However, this correlation fell to a nonsignificant -.41 when the 6 subjects in the higher IQ range were considered alone and rose to -.98 for the 6 lower IQ subjects. A similar finding occurred in the studies of Hartnoll (1978, cited in Brand, 1981), Grieve (1979, cited in Brand, 1981), and Deary (1980, cited in Brand & Deary, 1982), whereas Hosie (1979, cited in Brand, 1981) obtained a correlation of -.78 between IQ (extrapolated from subjects' scores on the Coloured Progressive Matrices) and IT, which was consistent across the entire IQ range of the 12 4-year-old subjects.

Contrary to the finding of Nettelbeck (Nettelbeck & Lally, 1976) two of these studies (Hartnoll, 1978 and Grieve, 1979, cited in Brand, 1981) demonstrated a greater association between verbal abilities (a composite of three measures; vocabulary, verbal fluency and verbal ability; Mill Hill Vocabulary) and IT than spatial abilities (Thurstone's Spatial Ability; Revised Minnesota Paper Form Board). Also Deary (1980, cited in Brand & Deary, 1982) found a high correlation of -.72 between IT and general ability as measured by Raven's Progressive Matrices together with a correlation of -.69 for IT and verbal ability (Mill Hill Vocabulary). Again these correlations fell substantially when formally retarded subjects were excluded.

Several criticisms have been made regarding these early studies, in particular the small, unrepresentative samples including mentally subnormal subjects, which have tended to inflate the correlations between IQ and IT (Mackintosh, 1981). Both Nettelbeck (1982) and Brand (Brand & Deary, 1982) are in agreement with Mackintosh's criticisms, but view them with varying degrees of concern, which reflects their theoretical perspectives. Nettelbeck (1982) goes to some lengths to show that no reliable evidence exists for a strong association between IT and IQ within the average and above-average IQ ranges. Further analysis of earlier data was carried out to show a similar trend to that found in Brand's studies in falling correlations for nonretarded subjects, with a drop in the IT-IQ relationship from a significant -.80 to a nonsignificant -.23 (Nettelbeck & Lally, 1981). The degree of association between IQ and IT was also tested for a sample of 56 university students. In this study general ability (Raven's Advanced Progressive Matrices) failed to correlate significantly with IT ($r = -.20$) and verbal ability (ACER-AL) only just reached significance ($r = -.34$) (Nettelbeck, 1982). Nettelbeck (1982; Nettelbeck & Kirby, 1983a,b), therefore, cautions against combining retarded and nonretarded subjects in future experiments if analysis is to be based on linear regression and against proposing IT as a culture fair index of intelligence.

Brand (Brand & Deary, 1982), on the other hand, argues that even if the artificially wide spread IQs were corrected for heterogeneity, the average correlation would still be around -.7. Further, by taking into consideration the possibility of depressed correlations due to the less than perfect internal consistency of the two variables, a more valid estimate of the IT-IQ correlation would be -.85. It is Brand's belief that the problems attendant on the small samples used in his studies are substantially offset by the overall resilience of the IT-IQ association in the face of the minor procedural variations adopted.

Nonetheless, subsequent research conducted with samples of average and above-average intelligence has typically demonstrated a smaller association between IT and IQ (Vernon, cited in Jensen, 1981; Vernon, 1983; Hulme & Turnbull, 1983; Smith & Stanley, 1983; Irwin, 1984; Nettelbeck & Kirby, 1983a). The only significant IT-IQ correlation among the four adult studies mentioned here, using university students as subjects and the Advanced Progressive Matrices as the IQ measure, was that found by Vernon (cited in Jensen, 1981) with a correlation of -.31 for a sample of 25. Nettelbeck and Kirby (1983a) obtained a nonsignificant correlation of -.20 for a sample of 59, whereas Irwin's (1984) study produced a correlation of -.09 for a sample of 27 which is not significantly different from zero, and Vernon (1983) reports that out of five cognitive variables measured in his study with a sample of 100, IT was the only variable which did not correlate with IQ. Nettelbeck and Kirby's (1983a) study, in fact, measured three groups of subjects: handicapped workers, trade apprentices and university students, and again demonstrated that the IT-IQ correlation is inflated when such groups are combined, with an overall correlation of -.48 significant at the .01 level.

These findings are consistent with Nettelbeck's (Nettelbeck & Lally, 1981) view that IT might not vary to any large extent among samples of average or above-average intelligence, although it varies considerably between samples of average and below-average intelligence. Vernon (1983) concludes that IT is a "threshold variable which can only successfully distinguish retarded and nonretarded samples, while within either group, or at least within a group of above-average intelligence, it does not appear to correlate with measures of intelligence nor with other measures of cognitive processing" (p.68).

A similar pattern of results has been found with the few recent child studies noted. Hulme and Turnbull (1983) investigated a representative sample in the normal population with 65 6- and 7-year-olds, with the intention of ascertaining whether IT relates more closely to measures of Performance or Verbal IQ (shortened form of the WISC-R). Overall IQ did not correlate significantly with IT (r = -.20) nor did Verbal IQ (r = -.08), but there was a small significant correlation between IT and Performance IQ (r = -.29). Their second experiment looked at a mentally subnormal sample of 8 children with PIQs ranging from 41 to 86. In this group the IQ-IT correlation reached a significant -.71, illustrating again that the IQ-IT association is at its strongest and most robust in the mentally retarded population.

Smith and Stanley (1983) correlated IT with general ability (Cattell Culture Fair Test) verbal ability (Progressive Achievement Tests of Reading Comprehension and Vocabulary) and Performance IQ (3 subtests WISC-R) for a mixed sample of 107 12-year-olds with IQs ranging from 59 to 142. All failed to reach significance, the closest being general ability with -.12, whereas Picture Completion was zero and the remainder positive (Block Design +.18; Mazes +.17; Comprehension +.04; Vocabulary +.12). These results are unusually poor, and may reflect the fact that no practice session was incorporated into the procedure of this study. This may have resulted in a degree of unreliability in the IT measures as suggested by the large standard deviation (105, mean 126).

Irwin (1984) carried out two experiments to test the size of the correlations between IT and both verbal (Mill Hill Vocabulary) and general ability (Raven's Matrices) in a normal sample of 12-year-olds. In the first experiment 50 children were tested with alphanumeric stimuli for one block of 100 trials, which resulted in a significant correlation with general ability (r = -.34) and a nonsignificant correlation with verbal ability (r =-.25). However, the means and standard deviations were excessively large and the distribution markedly skewed. Irwin's explanation is that such skewness is not uncommon in timed performances and the longer mean inspection times could be due to lack of practice. Consequently, a second experiment was conducted using two blocks of 100 trials with 25 children of average IQ. The skewness was reduced as well as the means and standard deviations, particulary between the first and second measure, but neither correlation was significant. If anything the relation between this measure of intelligence and IT came closer to zero as a result of more practice on the task. Nettelbeck (in press) considers that these results may be due partially to the degree of difficulty involved in identifying alphabetic characters, requiring several inspections in order to offset levels of internal noise.

Doyle (1986), on the other hand, has recently found highly significant correlations for Full Scale IQ (r =-.56) and both Verbal and Performance IQ (both r =-.51) on the WISC-R, offering clear support for Brand's theory that IT is an index of general intelligence.

Typically IT has been measured in the visual modality but use of both the auditory (Deary, 1980, cited in Brand & Deary, 1982; Irwin, 1984) and the tactile (Nettelbeck & Kirby, 1983a) modalities have been reported with varying results. Deary (1980, cited in Brand & Deary, 1982) reported that auditory IT (the shortest duration of two successive tones of different frequency at which subjects could correctly state the order of presentation) correlated -.66 with Verbal IQ, -.70 with Raven's Matrices, and +.99 with visual IT. However, the sample was small (n=13) and included mentally retarded subjects. Results that would seem to refute this position were reported by Irwin (1984). In his study, auditory IT correlated -.43 and -.24 with Verbal IQ and Raven's Matrices, respectively, and only +.05 with visual IT. In addition, these correlations were obtained from a larger (n=47) and more representative sample than that studied by Deary. Inspection time was measured in the tactile modality by Nettelbeck and Kirby (1983a), who do not consider it a promising method of estimating the rate of information processing because the subjects found the task difficult and their fingers became numb. Nevertheless, correlations between tactile and visual IT were statistically significant for all three subject groups (handicapped workers, trade apprentices, and university students) and the overall tactile IT-IQ correlation was higher than the overall visual IT-IQ correlation (r = -.71 compared with r = -.48), whereas tactile and visual IT-IQ correlations for university students were similar (r = -.17 compared with r = -.20).

Thus, it can be seen that the correlations between measured intelligence and IT have varied considerably from one study to another, with high correlations in some and practically none in others, and with different aspects of intelligence. In their review of the IT literature, Lubin and Fernandez (1986) claim that the overall results seem to indicate that factors of general intelligence and performance intelligence underlie IT whereas the verbal factor is not clear. Also, Nettelbeck (in press) has derived a coefficient of -.5 from currently available research to estimate the overall strength of the IT-IQ relationship among normal adults. He argues, however, that the results from the small number of studies with children remain ambiguous with respect to the IT-IQ correlation.

1.4 STRATEGIES

Most IT tasks employ a backward mask to control stimulus exposure durations and this aspect of procedure has resulted in a methodological problem for the IT paradigm. As early as 1982 (Nettelbeck et al) it was noted that some subjects develop strategies which enable them to make use of sources of information other than the briefly exposed stimulus figure, such as subtle post-masking cues associated with apparent movement and small changes in brightness, even when the mask seems effective for most subjects.

This phenomenon has been investigated directly by Mackenzie and Bingham (1985) who measured IT among a sample of 29 university students (WAIS mean IQ = 116.2, SD = 8.4) on a fully computerised task. They ascertained by self-report which subjects naturally used an apparent motion strategy and then attempted to train the non-users. However, it was found that the strategy could not be taught; subjects could either use it or not, independent of their measured intelligence. As predicted, the mean IT for strategy users (n=16) was significantly lower than that for non-users (n=13) and whereas no significant IT-IQ correlations were found for the former, among the latter IT was highly correlated with Peformance IQ and especially with scores on the Block Design and Object Assembly WAIS subtests (r = -.72, -.76, and -.75, respectively).

This study has shown that there are qualitative differences within a normal sample of subjects in the extent to which an effective strategy for performing an IT task can be applied, which are not related to differences in levels of IQ. Therefore, these individual differences may be causal in the breakdown of the IT-IQ association within nonretarded samples, especially since amongst a high IQ sample IT is still significantly related to IQ for those unable to make use of apparent motion cues (Egan, 1986).

Subsequent studies have confirmed this finding (Mackenzie & Cumming, 1986; Doyle, 1986). With a similar sample of mostly university students Mackenzie and Cumming (1986) found a high correlation between IT and scores on the Advanced Progressive Matrices for their 15 cue non-users (r = -.66) and a nonsignificant correlation (r = -.19) for their cue users (n=22). Doyle (1986) using a similar computerised procedure investigated the effect with a normal 12-year-old sample to find that the IT of cue non-users (n=22) correlated significantly with Full Scale, Verbal and Performance IQ on the WISC-R (r = -.66, -.65, and -.60, respectively) whereas the correlations for cue users (n=16) were again not significant. It is apparent, therefore, that the relationship between IT and IQ is critically dependent on the effective operation of the masking procedure.

Various attempts have been made to avoid the confounding effects of apparent motion by devising a target/mask combination which minimises the availability of such a cue, none of which have been entirely successful; some subjects still manage to use apparent motion or depth cues (Doyle, 1986; Turner, 1986; Longstreth et al, 1986). This suggests that the distinction between cue users and non-users is not an artifact of a particular set of stimuli, but may point to a more fundamental difference between people.

As yet no adequate explanations have been put forward as to why some subjects see apparent motion cues and others do not, but that it is a procedural flaw in the standard IT task is evident.

Nonetheless, despite the procedural problems, inspection time stands as an experimental measure with a clear information processing rationale that is unusual in being robustly related to IQ. This suggests a greater possibility than before in using it to investigate the specific information processing components involved in intelligent performance.

CHAPTER 2

SPECIFIC READING DISABILITY

2.1 DEFINITION

Specific reading disability, sometimes called developmental dyslexia, refers to a retardation in reading which is not explicable in terms of general intelligence (Rutter, Tizard & Whitmore, 1970) or other conventional causes of reading disability.

Attempts to define dyslexia have been hindered by a lack of agreement on terminology, diagnostic criteria, conceptualisation, and even the actual existence of the disorder by the major interested professional groups particularly educators, physicians, and psychologists. Critchley and Critchley (1978) have likened the usefulness of the debate over the term dyslexia to that of ecclesiastics in the Middle Ages hotly disputing how many angels could stand on the head of a pin. Critchley and Critchley see denial of the existence of the disorder as an excuse for inaction. However that may be, as a result of this disagreement, definitions tend to state what dyslexia is not rather than what it is.

The most widely employed of such exclusionary definitions is that published by the World Federation of Neurology in 1968, which states:

> Specific Developmental Dyslexia [is] a disorder manifested by difficulty in learning to read despite conventional instruction, adequate intelligence, and socio-cultural opportunity. It is dependent upon fundamental cognitive disabilities which are frequently of constitutional origin (in Critchley, 1970, p.11).

Both Rutter (1978) and Eisenberg (1978) have criticised this definition on the grounds that it adds nothing to conceptual clarity because the key terms are so imprecise and unspecified. Further, it implies that children with below average intelligence, from poor or disadvantaged backgrounds, with inadequate schooling cannot be diagnosed as specific reading disabled.

According to Hynd and Cohen (1983), the best definition of dyslexia yet advanced was developed by a task force of the International Reading Association. Their definition is as follows:

> *Dyslexia:*
>
> 1. n. A medical term for incomplete alexia; partial but severe, inability to read; historically (but less common in current use), word blindness. *Note:* Dyslexia in this sense applies to persons who ordinarily have adequate vision, hearing, intelligence, and general language functioning. *Dyslexia is a rare but definable and diagnosable form of primary reading retardation with some form of central nervous system dysfunction. It is not attributable to environmental causes or other handicapping conditions.*
>
> 2. n. A severe reading disability of unexpected origin.
>
> 3. n. A popular term for any difficulty in reading of any intensity and

> from any cause(s). *Note:* Dyslexia in this sense is a term which describes a symptom, not a disease (in Hynd & Cohen, 1983, p.10).

This definition is objective and specific enough for general diagnostic purposes and, at the same time, differentiates between popular and professional usage. Most importantly, it clearly separates developmental (primary) dyslexics, whose difficulties are endogenous or innate, from the larger overall group of disabled readers (secondary dyslexics), whose disability is the product of unpropitious environmental factors including brain damage (Critchley & Critchley, 1978).

Rutter and Yule (1975) have differentiated two groups of poor readers along similar lines in their epidemiological studies of children on the Isle of Wight and in London. They distinguish between "backward readers" who experience difficulties in most academic areas and "specifically reading retarded" or "developmental dyslexic" children who experience difficulties only with printed words. Their results show that reading backwardness is present in both boys and girls and is usually accompanied by one or more of a wide range of neurological dysfunctions and low intelligence. It is most commonly found in children from large, low socio-economic status families. Specific reading retardation, on the other hand, is much more common in boys (a ratio of 3.3:1), is not often associated with overt neurological disorders and is more specifically associated with delays in the development of speech and language. It is also more common in large families regardless of socio-economic status. In addition they found that the specific-reading-disabled children made less progress in reading and spelling than backward readers over a four- to five-year period, even though they had higher intelligence quotients. At the same time they did make more progress in mathematics, which points to the highly specific nature of reading retardation.

Although Yule and Rutter (1976) argue against the concept of dyslexia, their research stands out as truly important. They document that a significant percentage of school-age children with normal intelligence do, in fact, experience failure in reading attainment. Rutter (1978) considers it unrealistic to estimate the prevalence of dyslexia until the disorder can be identified by some valid biological or behavioural marker. Nevertheless, estimates of the prevalence of school-age children who fall into this category range from about 3.7% (Rutter et al, 1970) to 15% (Duane, 1974).

For the purposes of research specific reading disability is operationally defined in terms of specific criteria such as those outlined by Stanley and Hall (1973a,b). Criteria usually include the gap between the actual and expected reading ages, average or better performance in other academic subjects and average or better intelligence as measured by a non-verbal intelligence test, absence of gross behavioural problems, absence of organic disorders and at least normal visual acuity. Thereby, secondary dyslexics are excluded. Again, lack of consistency in the stringency of these criteria across studies inevitably leads to conflicting findings.

2.2 THEORIES

As can be seen by the problems encountered in finding an adequate definition for specific reading disability (SRD) or developmental dyslexia, the area is fraught with controversy. This controversy is generated by the plethora of theoretical explanations regarding SRD which abound in the research literature and which can be subsumed under two main headings: multifactor theories and unitary theories.

Multifactor theorists suggest that the etiology of specific reading disability is heterogeneous in nature, there being different types of reading disability displaying different symptoms and presumably arising from different causes. Various approaches have been adopted by researchers who attempt to classify SRDs into subtypes, but categorisation is usually made either on the basis of neuropsychological and psychometric measures such as language ability, memory capacity, and perception (Denckla, 1972; Kinsbourne & Warrington, 1963; Mattis, 1978; Mattis, French & Rapin, 1975; Pirozzolo, 1979), or on the basis of reading related achievement measures, for example word recognition, comprehension, and spelling (Boder, 1971; 1973; 1982; Doehring & Hoshko, 1977; Satz & Morris, 1981). Although there are some similarities between the categories outlined in a number of these studies, perfect agreement has not been reached yet concerning subtypes of reading disabilities.

The unitary concept of SRD views reading disability as stemming from a single underlying cause and, according to Hynd and Cohen (1983), comprises the largest collection of hypothesised explanations for this disorder. Four main areas of research are included within the concept: cerebral dominance, psychological processes related to visual and auditory perception (including the visual deficit hypothesis), cognitive processes such as memory, and brain pathology. While all of these theoretical approaches differ with regard to the proposed underlying cause of SRD, they all hold three main assumptions:

1. that the population of SRD children is a homogeneous, etiological and clinical entity, exhibiting a random distribution of characteristic errors in reading,
2. that the appropriate methodology is a comparison of levels of performance between SRDs and controls on a particular task thought to be related to reading achievement, and
3. that there is some form of neurological dysfunction (deficit or delay) as the underlying basis for the reading disability.

Brain function theories propose that the cause of reading disability can be found in the neurology or anatomy of the brain, whereas cerebral dominance theories suggest that there is a developmental lag in cerebral dominance and processing inadequacies in either the left or right hemishphere (Hynd & Cohen, 1983). Cognitive and psychological theories include deficiencies in temporal order perception, intersensory integration, visual processing, and verbal processing (Vellutino, 1979). Each of these theories has a substantial body of research to commend it, but the particular theory of interest to this study is the visual deficit hypothesis.

2.2.1 The Visual Deficit Hypothesis

In so far as reading involves visual processing, it is an obvious step to suppose that the visual system is implicated in the disorder in some way. Hence, the popularity of this theory. However, research in support of such a perceptual deficit has proved equivocal (Benton, 1962, 1975). The work of Vellutino and his colleagues (Vellutino, 1978, 1979; Vellutino, Smith, Steger & Kaman, 1975; Vellutino, Steger & Kandel, 1972; Vellutino, Steger, Moyer, Harding & Niles, 1977) has led him (Vellutino, 1978) to suggest that reading is primarily a linguistic skill and that the problems experienced by SRDs, particularly orientation and sequencing errors, can more adequately be explained in terms of deficiencies in verbal processing than in terms of deficiencies in visual processing.

However, recent proponents of the visual deficit hypothesis, namely Lovegrove, Martin and Slaghuis (1986), have implicated lower level sensory processes in the visual system as playing a role in specific reading disability along with putative higher level cognitive processes. Their experimental work was conducted within the spatial frequency analysis framework and their results were explained in terms of sustained and transient subsystems within the visual system. Their findings indicate that SRDs may have a deficit in one of these subsystems, that is the transient system.

The following three sections will outline the background research regarding the existence of spatial frequency channels themselves and the characteriestics of the transient and sustained subsystems, as well as the current evidence for a transient mechanism deficit in SRDs.

2.2.1.1 Spatial Frequency Analysis in the Visual System

The analysis of visual information passing through the neurophysiological network of the visual system has proved difficult to trace. One early hypothesis based on electrophysiological single cell studies in infrahumans like those of Hubel and Wiesel (1962, 1968) speculated that the brain analyses and recognises visual images in terms of their features, for example, bars and edges of specific dimensions, orientations, locations, and velocities. This approach is appropriately called feature analysis. Recent psychophysical, electrophysiological, and anatomical research, on the other hand, suggests the existence of parallel pathways or channels in the human visual system, the functional role of which is explained in two ways. One approach proposes that the visual system, rather than responding to features, performs a generalised transformation of the retinal luminance distribution in terms of a Fourier analysis, in which a complex stimulus is analysed into its component sinusoidal luminance distributions (Campbell & Robson, 1968; Pollen, Lee & Taylor, 1971; Weisstein, 1980). The other approach assumes that the visual system filters complex input into the responses of the spatial frequency and orientation selective channels, which act as detectors and analyse stimuli into different scales for later processing, that is spatial frequency analysis (Barlow, 1972; Graham, 1980; Maffei & Fiorentini, 1973; Shapley & Lennie, 1985; Wilson, 1978). However, for the purposes of this study, the resolution between these two approaches is not crucial.

A channel may be defined as a stimulus-response mechanism that responds better to certain stimuli than to others (Shapley & Lennie, 1985). In physiological terms a channel can be described as a collection of cells which have receptive fields that are identical in terms of their selectivity for size, shape, and orientation, differing only in terms of their position on the retina, so that information is able to be gathered from the whole visual field (Graham, 1980).

Much of the evidence for the existence of these spatial frequency-orientation channels is derived from experiments employing gratings, each parameter of which can be changed independently of the other for example: spatial frequency (number of cycles per degree of visual angle), orientation (number of degrees to left or right of vertical), contrast (differences between maximum and minimum luminances), phase (position), and luminance.

Using such gratings it has been demonstrated electrophysiologically that single cells in the visual system of the cat (Campbell, Cooper & Enroth-Cugell, 1969; Enroth-Cugell & Robson, 1966) and squirrel-monkey (Campbell, Cooper, Robson & Sachs, 1969) are responsive to only a limited range of spatial frequencies. It has also been shown that cortical cells in cats and monkeys are orientation selective, whereas precortical cells are generally insensitive to orientation (Hubel & Wiesel, 1962, 1968).

Psychophysical studies, on the other hand, have shown evidence of spatial frequency channels in humans. The general finding appears to be that the visual system does not operate as a single detector mechanism preceded by a single broad-band spatial filter, but as a number of independent detector mechanisms each preceded by a relatively narrow-band filter "tuned" to a different frequency (Campbell & Robson, 1968). Thus, each filter and detector constitutes a separate channel with its own contrast sensitivity function (CSF).

Following on from this finding, an attempt was made by Blakemore and Campbell (1969b) to measure more quantitatively the properties of these spatial frequency selective neurones. First, it was demonstrated that an observer's sensitivity for a grating can be impaired by prior adaptation to a pattern of identical orientation and spatial frequency (Blakemore & Campbell, 1969a). Then, utilising this spatial-adaptation effect, Blakemore and Campbell (1969b) measured the range of spatial frequencies to which sensitivity was reduced by adaptation to a test grating of a specific spatial frequency. They found that each channel is optimally responsive to a given spatial frequency ranging from 3 c/deg to 48 c/deg and has a bandwidth of $\pm$ 1 octave. Gilinsky (1968) and Caelli and Bevan (1983) have also shown that each channel responds only to a narrow range of orientations, approximately 15 degrees on either side of the channel's preferred orientation.

More direct evidence has been made available by electrophysiological and anatomical studies in humans. Campbell and Maffei (1970) developed an electrophysiological technique which allowed them to measure evoked potentials from the human scalp adjacent to the visual area of the brain. This eliminated subjective reports and confirmed that neurones highly selective to both spatial frequency and orientation do exist. Bodis-Wollner (1972), on the other hand, investigated patients with temporary lesions involving the visual pathways, who complained of blurred vision and an occasional inability to read despite good visual acuity and lack of retinal pathology. An examination of their CSFs on admission revealed that they experienced an overall loss of sensitivity with a relatively greater loss at high spatial frequencies, and with treatment their CSFs returned to normal. This nonuniform alteration in contrast sensitivity was interpreted as an indication of independent channels with different spatial frequencies.

In conclusion, there is substantial physiological, electrophysiological and anatomical evidence consistent with a multichannel spatial frequency analysis within the visual system.

The next step in research was to investigate the spatio-temporal properties of these spatial frequency and orientation selective channels. This took the form of two streams of investigation; the electrophysiological and the psychophysical. Electrophysiological studies investigate the relationship between responses of single cells and networks of such cells to visual information processing in a number of infrahuman species (Grinvald, 1985), whereas psychophysical studies use human subjects to investigate the operation of arrays of visual neurones at various levels of the visual system which perform a generalised transform of the visual input (Ganz, 1975). While it is assumed that the response properties of single cells in humans may be inferred from the perceptual data of these psychophysical studies, there is also an attempt to correlate observations made at these two different levels of analysis. The rules that relate the visual events to their physiological correlates are known as psychophysical linking hypotheses (Sekuler, 1974; Weintraub, 1975).

2.2.1.2 X and Y Cells in the Visual System

Initially, Enroth-Cugell and Robson (1966) provided electrophysiological evidence for a classification of cat retinal ganglion cells in terms of their spatial summation properties. They distinguished between two types of cells: X cells which exhibited linear spatial summation across the antagonistically organised receptive fields and Y cells which displayed a non-linear spatial summation. In other words, X cells responded to the prolonged presentation of a grating in a sustained manner throughout the presentation of the grating, whereas Y cells responded in a transient fashion to the onset and offset of the grating.

Subsequent electrophysiological studies have used other methods in the classification of these X and Y cells in the retinal ganglia of cats, including the respone of X and Y cells to diffuse light (Fukada, 1971), their response to drifting gratings (Cleland, Dubin & Levick, 1971), their response to flashes of light (Cleland et al, 1971; Cleland, Levick & Sanderson, 1973) and their response to flickering gratings (Fukada & Saito, 1971). All these studies have demonstrated that X cells respond maximally to relatively high spatial and low temporal frequencies (gradual on- and off-set stimuli) whereas Y cells are tuned to low spatial and relatively high temporal frequencies (short duration stimuli with sudden on- and off-sets). On the basis of their temporal properties, Cleland et al (1971) introduced the terms "sustained" and "transient" to characterise the two cell types.

This new terminology was adopted readily by the psychophysicists. However, although sustained and transient cells appear to have a number of properties in common with X and Y cells and were originally taken as being the same, it is now considered that the X-Y classification describes a cell-type, whereas the sustained-transient classification describes the behavioural properties of cell responses. Other terms such as Type I and Type II cells or phasic (Type I, Y, transient) and tonic (Type II, X, sustained) cells are also found in the literature (Fukada, 1971; Fukada & Saito, 1971; Gouras, 1968).

Both X and Y cells have been found in the visual pathways of cats at all levels of visual processing from the retinal ganglion cells (Enroth-Cugell & Robson, 1966; Cleland et al, 1973) to the lateral geniculate nucleus (LGN) (Cleland et al, 1971) to the visual cortex (Ikeda & Wright, 1974; Movshon, Thompson & Tolhurst, 1978). This means that the transient-sustained response dichotomy is relayed in parallel channels from the retina, through the LGN to the visual cortex. The axons of sustained cells have been found to conduct more slowly than those of transient cells (Cleland et al, 1971; Fukada, 1971; Hoffman, 1973; Hoffman & Stone, 1971), so that it may be inferred that information transmitted by the latter will reach the cortex first (Ikeda & Wright, 1972).

2.2.1.3 Sustained and Transient Mechanisms in the Visual System

In parallel with the electrophysiological findings, varying types of psychophysical experiments have provided evidence for sustained and transient mechanisms in the human visual system. These have been summarised by Legge (1978) under five headings: (1) distinct thresholds for perceiving temporal and spatial modulation, (2) subthreshold summation experiments, (3) response latency experiments, (4) thresholds for different temporal waveforms, and (5) spatial frequency thresholds as a function of signal duration. Data from all these areas have led researchers (King-Smith & Kulikowski, 1975; Kulikowski & Tolhurst, 1973; Tolhurst 1973) to conclude that sustained channels predominate in pattern perception and transient channels provide general shape and movement information.

(1) In temporal modulation studies several investigators (Keesey, 1972; King-Smith & Kulikowski, 1975; Kulikowski & Tolhurst, 1973; Nes, Koenderink, Nas & Bouman, 1967; Tolhurst, 1973; Tolhurst, Sharpe & Hart, 1973) have reported that subjects can distinguish two thresholds, one at which temporal variation can be perceived (flicker) and one at which the spatial structure is distinct (pattern). These flicker detection and pattern recognition thresholds vary independently as functions of the spatial and temporal frequencies, suggesting that the two thresholds represent the activity of two independent systems. Flicker sensitivity is ascribed to a transient mechanism because it is tuned to low spatial frequencies (lowpass spatially) and relatively high temporal frequencies (bandpass temporally). Pattern sensitivity is ascribed to a sustained mechanism because it has a bandpass spatial frequency and a peak at lower temporal frequencies (Kulikowski & Tolhurst, 1973).

(2) Tolhurst (1975b) in a subthreshold summation task found evidence suggesting sustained mechanisms detect long duration stimuli at high spatial frequencies whereas at low spatial frequencies with shorter durations (below 100 msec) transient mechanisms seem to be implicated. King-Smith and Kulikowski (1975) in a further subthreshold summation task found that pattern detecting mechanisms show linear spatial summation, whereas flicker detecting mechanisms demonstrate characteristics of non-linear spatial summation.

(3) Differential processing times between transient and sustained channels which were originally demonstrated by electrophysiological measures of conduction times (Cleland et al, 1971; Fukada, 1971; Hoffman, 1973; Hoffman & Stone, 1971) have been manifested in response latency experiments. Breitmeyer, (1975), Luppe, Hauske and Wolf (1976) and Vassilev and Mitov (1976) observed that reaction times for the detection of high spatial frequency gratings are longer than for low spatial frequency gratings, and suggested that sensitivity at high spatial frequencies is mediated by sustained neurones with slow conduction velocities.

(4) By measuring an observer's reaction times to near-threshold contrasts of stimuli consisting of sinusoidal gratings with either gradual or abrupt onsets and offsets, Tolhurst (1975a) demonstrated that the speed of response was dependent on the sustained or transient characteristics of the neural pathways most sensitive to the given stimulus. Thus the reaction time histogram for the detection of low spatial frequency gratings was bimodal, one mode corresponding to a cluster of reaction times at stimulus onset and the other at stimulus offset. This is consistent with the proposed properties of transient channels. On the other hand, reaction times to high spatial frequency gratings produced a unimodal distribution, as would be expected of sustained channels.

(5) Results from experiments measuring spatial frequency thresholds as a

function of signal duration have proved equivocal. According to Legge (1978), threshold contrast for transient mechanisms should only decrease with signal duration up to some critical duration, which is characteristic of the temporal integration period of that mechanism. Beyond this criterion it should be independent of signal duration. For sustained systems, on the other hand, it would be expected that sensitivity to a stimulus should steadily increase as a function of its signal duration, because the longer the stimulus duration, the greater the probability that the system threshold will be exceeded. Only the studies of Legge (1978), Nachmias (1967) and Spitzberg and Richards (1975) have yielded data suggestive of a dichotomy in the shape of threshold curves at low and high spatial frequencies. Breitmeyer and Ganz (1977) and Brown and Black (1976) found the period of temporal summation to be shorter for low than for high spatial frequencies, but found no discontinuity in the shape of the function indicative of two separate channels. Whereas Keesey and Jones (1976) found no significant effect of spatial frequency at all, though, as Legge (1978) suggests, their lowest spatial frequency of 1.5 c/deg may not have been low enough to activate the transient mechanisms.

Further psychophysical research (Harwerth & Levi, 1978) has tended to corroborate the findings of electrophysiological studies on cats (Enroth-Cugell & Robson, 1966; Fukuda & Stone, 1974; Hoffman, Stone & Sherman, 1972) that the transient system dominates in peripheral vision and the sustained in central or foveal vision. Also the transient system does not appear to be colour selective whereas the sustained system is (Sharpe, 1974; Tolhurst, 1977).

To summarise, the sustained mechanism appears to mediate pattern detection in that it is more sensitive to high spatial frequencies (e.g., fine details), pattern, low temporal frequencies and foveal vision, has slower transmission times and responds throughout stimulus presentation. Conversely, the transient mechanism seems to subserve movement detection in that it is more sensitive to low spatial frequencies (e.g., shapes), flicker, high temporal frequencies and peripheral vision, has faster transmission times and responds at the onset and offset of a stimulus presentation.

Recently, the simplicity of this functional dichotomy has been questioned. Psychophysical evidence from the masking-by-light experiments of Green (1984) suggests that both mechanisms are capable of mediating motion perception. Studies by Lovegrove and his co-workers (Lovegrove & Evans, 1980; Lovegrove, Mapperson & Bowling, 1980), who found that the sustained system can process motion information with gratings of low temporal modulation, support this notion. Likewise, several researchers (Burbeck, 1981; Derrington & Henning, 1981) have proposed that the transient system also transmits some pattern information. This is substantiated by the physiological study of Lennie (1980a), who found that Y cells are no less sensitive than X cells to stimuli of low temporal frequency, when the temporal contrast sensitivities of X and Y ganglion cells in the cat are measured with similar stimuli to those used in psychophysical experiments. Therefore, the assumption that X cells are the physiological substrates of sustained responses which mediate spatial vision and Y cells are the physiological substrates of transient responses which mediate temporal vision may not be as straightforward as has previously been suggested (Lennie 1980b). Nevertheless, this recent evidence does not argue against the sustained-transient model, it merely points to a less discrete dichotomy of function.

One other characteristic of the sustained and transient mechanisms, the importance of which will become apparent in the following discussion on transient system deficits in SRDs, is their ability to inhibit one another. Normally, the inhibitory interaction is transient-on-sustained (Breitmeyer & Ganz, 1976), but there is evidence to show that inhibition of a reverse nature can also occur (Breitmeyer, 1978; Georgeson, 1976).

Thus, the sustained mechanism predominates in processing spatial information and the transient mechanism predominates in processing temporal information. Together they interact to provide the visual system as a whole with optimum information, encoding good spatial and good temporal resolution in a complimentary fashion. Consequently, if a deficit were to be found at this low level of visual processing in the visual systems of SRDs, information processing deficits would be expected to manifest themselves in various forms.

2.2.1.4 A Transient Mechanism Deficit and Specific Reading Disability

The process of reading involves a series of fixations each of which is separated by a brief eye movement or "saccade". The average duration of a fixation pause is approximately 200-250 milliseconds and it is during these pauses that information from the printed page is observed. The following saccades, lasting between 20 and 50 milliseconds (Breitmeyer & Ganz, 1976), suppress this visual information and allow time for unidentified regions of text to be brought into foveal vision (the central, high acuity visual area) for detailed analysis during the next fixation (Lovegrove et al, 1986).

Breitmeyer (1980; Breitmeyer & Ganz, 1976) has explained this saccadic suppression in terms of metacontrast which is itself explicable in terms of transient-on-sustained inhibition. During each fixation there is a sustained channel reaction which, due to visible persistence, may continue to respond after the physical duration of the stimulus. The saccade then triggers transient responses throughout the saccade, effectively terminating the visible persistence activated by the sustained response of the previous fixation, and preventing the superimposition of the succeeding one (Breitmeyer & Ganz, 1976; Matin, 1974). The interaction of these two systems results in a series of clear, unmasked and temporally segregated frames of sustained activity, each representing the pattern information obtained in a single fixation. Information obtained from successive fixations is then integrated to form a meaningful whole.

However, if the transient system were deficient, transient-on-sustained inhibition may not be effective in terminating visible persistence. This would result in the input from one fixation degrading that from the next in some way, causing the text to become blurred and mutilated. Such stimulus congestion is often reported by SRDs (Jackson, 1976). Indeed, it has been shown in tasks where saccades are not required, for example in letter or word recognition tasks when the stimuli are presented singly in spatial isolation, that SRDs frequently perform at least as well as controls (Vellutino, Pruzek, Steger & Meshoulam, 1973; Vellutino, Steger, Kaman & DeSetto, 1975). Consequently, Lovegrove and his colleagues (1986) have hypothesised that SRDs may suffer from a low level visual processing deficit, that is a deficit in their transient mechanisms.

Most of the evidence for this hypothesis has come from experiments using visible persistence and contrast sensitivity functions (CSF) as tools for studying visual processing. Spatial frequency generated visible persistence has been investigated in eight (Lovegrove, Heddle & Slaghuis, 1980) nine (Slaghuis & Lovegrove, 1985) and fourteen (Badcock & Lovegrove, 1981) year-old disabled and normal readers. Although persistence increased in a linear fashion for both groups, the slope of the function was steeper for controls, indicating that SRDs have longer persistence than controls at low spatial frequencies and shorter persistence at high spatial frequencies. This effect was found to be greater at longer stimulus durations (200 - 350 msec but not less than 80 msec) and lower levels of contrast.

Lovegrove and his colleagues (1980b; 1986; Badcock & Lovegrove, 1981; Slaghuis & Lovegrove, 1985) have interpreted the persistence differences between SRDs and controls at low and high spatial frequencies in terms of two different types of transient-sustained interaction. "Tonic transient-on-sustained inhibition" refers to the transient system inhibiting the sustained system across the whole range of spatial frequency channels, whereas "phasic transient-on-sustained inhibition" refers to the transient system inhibiting the sustained system in low spatial frequencies only. Both of these involve a weak transient system but one occurs at high and the other at low spatial frequencies.

At low spatial frequencies it is hypothesised that the longer persistence durations in SRDs result from decreased phasic transient-on-sustained inhibition which enables the sustained system to respond for longer. At high spatial frequencies, on the other hand, it is hypothesised that tonic transient-on-sustained inhibition occurs normally. This would slightly decrease the activity of the sustained system compared to its activity in the absence of such inhibition. Such a decrease would lead to increased persistence since persistence is known to increase with decreasing stimulus or response intensity (Bowling and Lovegrove, 1980a,b; 1981). Thus, if SRDs have a weak transient system, their sustained system at high spatial frequencies should be disinhibited compared to that of controls. This would increase the firing rate of their sustained system (relative to controls) and produce shorter persistence durations.

Breitmeyer, Levi, and Harwerth (1981) have shown that by superimposing a uniform field cycling at 6Hz on the persistence task, normal transient channel involvement in persistence is reduced, resulting in increased persistence durations at low but not at high spatial frequencies. A similar technique was used by Slaghuis and Lovegrove (1984) to test the hypothesis of weak transient inhibition in SRDs. As predicted the flickering field influenced SRDs less than controls at low spatial frequencies, thereby reducing persitence differences between the two groups. This strongly suggests that SRDs and controls differ in their transient systems. Further, in controls the presence of the 6 Hz uniform field actually decreased persistence duration at higher spatial frequencies, supporting the hypothesis of tonic transient-on-sustained inhibition, whereas in SRDs it increased persistence duration indicating, according to Slaghuis and Lovegrove, the occurrence of adaptation within sustained channels through constant stimulation in the absence of much transient channel activity.

In comparisons of pattern CSFs in disabled readers and controls (Lovegrove, Bowling, Badcock & Blackwood, 1980; Lovegrove, Martin, Bowling, Blackwood, Badcock & Paxton, 1982; Martin & Lovegrove, 1984), SRDs were found to be consistently less sensitive than controls to low spatial frequencies. At higher spatial frequencies (12 - 16 c/deg), SRDs were either slightly more sensitive than controls (Lovegrove et al, 1982; Martin & Lovegrove, 1984) or the two groups did not differ in contrast sensitivity (Lovegrove et al, 1980a). The finding of a small but consistent sensitivity loss at low spatial frequencies in SRDs fits well with a proposed transient system deficit. Also, a similar explanation can be given for the finding that SRDs are more sensitive than controls at high spatial frequencies, if it is assumed that normally there is tonic transient-on-sustained inhibition at high spatial frequencies which is weak or absent in SRDs (Lovegrove et al, 1986).

Again, the hypothesis of weak transient inhibition in SRDs was tested with the presentation of a 6Hz masking field during the measurement of contrast detection thresholds in SRDs and controls (Martin & Lovegrove, 1985). At low spatial frequencies the uniform flickering field reduced sensitivity in controls but not in SRDs, whereas at high spatial frequencies the effect was reversed. Thus, the general effect of the masking field was to make the CSF of normal readers appear more like that of SRDs, indicating that the two groups differ in their transient systems.

Finally, the transient system deficit in SRDs has been investigated more directly by measuring flicker thresholds, which are considered to be mediated by the transient system (Keesey, 1972; Kulikowski & Tolhurst, 1973). Martin and Lovegrove (1987) measured flicker thresholds for a 2 c/deg grating with flicker rates varying from 5 - 25 Hz using a two-alternative forced choice procedure in SRDs and controls. The results showed that SRDs were less sensitive than controls at all temporal frequencies with differences being maximal at the highest temporal frequencies. In light of the evidence that transient channels are optimally sensitive to low spatial frequencies and high temporal frequencies (Kulikowski & Tolhurst, 1973; Tolhurst, 1973), these results indicate a major difference between the two groups in transient system functioning.

In a second experiment which determined flicker CSFs for the same two groups using spatial frequencies from 1 - 12 c/deg at 20 Hz, SRDs were found to be less sensitive than controls to counterphase gratings at all spatial frequencies with the differences being greater at the higher spatial frequencies. Although one would have expected the larger differences to have occurred at low rather than higher spatial frequencies, this result has been explained in terms of the hypothesis of tonic mutual inhibition between the sustained and transient systems on the grounds that the issue is complicated by the use of a rather high temporal frequency (20 Hz). According to Lovegrove and his colleagues (1986), "if SRDs have a deficient transient system, it may be inhibited more by the sustained system than would be the case in controls, especially at higher spatial frequencies. Consequently, at such spatial frequencies their sensitivity to flicker would be low both because of their deficient transient system and the resultant increased sustained-on-transient inhibition" (p. 247).

Taken all together this data points strongly towards a transient system deficit in SRDs, since in normal circumstances the transient mechanism responds optimally to low spatial frequencies and high temporal frequencies. Such a deficit has been implicated in the reading process in a number of ways (Badcock & Lovegrove, 1981; Lovegrove et al, 1986; Martin & Lovegrove, 1984; Slaghuis & Lovegrove, 1984, 1985). According to Breitmeyer's (1980; Breitmeyer & Ganz, 1976) model of transient-on-sustained inhibition, mentioned earlier, a deficit in the transient system may lead to the integration of information across fixations, producing a mutilated text. Integration may also occur within a fixation. It has been shown that normal readers use general peripheral information to aid recognition and to guide eye movements (Fisher, 1976; Inhoff & Rayner, 1980; Rayner, McConkie & Zola, 1980). This information is mostly transmitted by the faster acting low spatial frequency channels, which dominate in the periphery, whereas more detailed information is conveyed by the slower high spatial frequency channels dominating in the fovea (Breitmeyer & Ganz, 1976). A low spatial frequency (transient) deficit may, therefore, result in both low and high frequency information arriving at about the same time, which could prevent SRDs from utilising the general peripheral information.

In addition, reduced transient activity may slow down the temporal resolution of the visual system in SRDs, as has frequently been shown to occur (DiLollo, Hanson & McIntyre, 1983; Lovegrove & Brown, 1978). This slower temporal resolution may contribute to loss of visual information through masking by interruption before it can be converted into a speech form, resulting in a print-to-speech encoding deficit. Finally, there may be some similarity between the specific losses of spatial frequency sensitivity in SRDs and the cerebral lesion patients of Bodis-Wollner (1972). Despite little or no loss in visual acuity both groups experience difficulties in reading, so a nonuniformly altered contrast sensitivity may produce problems in pattern perception without necessarily limiting visual acuity.

CHAPTER 3

VISUAL MASKING

3.1 DEFINITION AND TYPES

Visual masking occurs when one visual stimulus interferes with the perception of another visual stimulus. Michaels and Turvey (1979, p.2) have defined masking as "the phenomenon of perceptual interference that results when temporally discrete, briefly exposed, and unrelated visual fields are presented in rapid succession to a stationary observer". The quantitative and qualitative characteristics of this perceptual interference are determined by the figural, spatial, temporal, and intensive characteristics of the interacting stimuli (Felsten & Wasserman, 1980). Thus, there are different types of visual masking.

Conventionally, the masking stimulus (MS) interferes with the perception of the target stimulus (TS), and, although mutual masking can occur, most experiments are designed so that masking is, in effect, unidirectional. Presentations of TS and MS are usually separated by a variable interval, which can be measured in one of two ways (Kahneman, 1968). Firstly, interstimulus interval (ISI) measures the time between the offset of the first stimulus and the onset of the second stimulus, and is generally used only in those situations in which the two stimuli do not overlap. Secondly, stimulus onset asynchrony (SOA) refers to the duration between the onsets of the two stimuli, and is a signed measure. Temporally, masking effects can be divided into two categories depending on whether the TS follows the MS or vice versa. Forward masking refers to the negative temporal relationship of target following mask, and backward masking is associated with the positive temporal relationship of mask succeeding target.

Spatially, four main types of target and mask stimuli have been used to achieve masking effects (Breitmeyer & Ganz, 1976; Felsten & Wasserman, 1980; Kahneman, 1968). When the contours of the mask do not overlap but are contiguous with the contours of the target, paracontrast or metacontrast masking occurs depending on whether masking is forward or backward, respectively. Masking in which the contours of the mask overlap the target and are structurally similar is called masking by structure or pattern. Whereas masking by noise refers to an overlapping mask with a completely random pattern, bearing little structural resemblance to the target; masking by light occurs when the mask is a more intense flash of light, illuminating a larger area than the target.

The combination of these types of masks and targets generally produce two masking functions, namely Type A and Type B masking (Breitmeyer & Ganz, 1976). In the former, masking magnitude shows a monotonic decrease with an increase in ISI or SOA. In other words, the effectiveness of the mask in reducing the clarity of the target is at a maximum when the temporal interval between target and mask is at a minimum. Thus, the peak masking effect occurs at SOA = 0 and there is much forward masking (Kahneman, 1968). Whereas, in the latter, masking magnitude varies in a non-monotonic, U-shaped function (or J-shaped function according to Michaels &

Turvey, 1979). Optimal masking effects occur at longer SOAs (50 - 100 msec), exerting little influence at short onset-to-onset intervals, and forward masking is weak or absent.

3.2 THEORIES

Visual masking has proved to be a useful analytic tool in the investigation of the visual system. Through the procedure of visual masking, it has been possible, on the one hand, to formulate many of the physiological mechanisms underlying people's perceptual abilities and, on the other hand, to examine the temporal stages of visual processing and thereby isolate discrete information processing stores. Historically, within these two frameworks, two alternative hypotheses have developed to explain how visual masking operates.

Essentially the information processing approach views visual perception as a hierarchically organised temporal sequence of events involving stages of storage and transformation of information. Thus, the normal perception of a TS requires a certain amount of processing time and that processing may be interfered with or terminated if another stimulus is presented during that necessary time. Sperling (1963) and Haber (1969) hypothesised that on the presentation of the TS a clear icon or representation is developed but information from this visual image is prevented from being transferred into a more permanent store by the subsequent arrival of the MS. They considered the mask to have no "backward" effect as such, but rather to serve as an interruption to the processing that began with the initial registration of the TS. This interpretation is known, therefore, as the interruption hypothesis.

The alternative view, referred to as the integration hypothesis, stresses the effect of masking on the sensory character of the visual representation itself. According to this hypothesis, when two stimuli follow each other in rapid succession, they synthesise and the visual system treats them as a single stimulus (Kahneman, 1968), producing an effect similar to that produced by the double exposure of photographic film (Felsten & Wasserman, 1980; Turvey, 1973). Whereas this hypothesis adequately explains both forward and backward masking, the interruption hypothesis only accounts for backward masking. However, Kahneman (1968) points out that because the MS is a more intense visual stimulus than the TS in most experiments, it is possible that the TS fails to be perceived in forward masking, because it is too weak a stimulus to interrupt the continued processing of the MS. Further, an interruption hypothesis of backward masking is not incompatible with an integration hypothesis of forward masking.

Recent theories of visual masking, for the most part, continue to be based either on an information processing approach (Michaels & Turvey, 1979; Turvey, 1973) or on a neurophysiological approach (Breitmeyer & Ganz, 1976; Felsten & Wasserman, 1980; Matin, 1975). Turvey (1973), who holds an information processing perspective towards visual masking phenomena, has suggested that rather than two opposing hypotheses, the integrative and interruptive mechanisms may occur together but tap different stages of visual processing. In a number of experiments Turvey (1973) showed that integrative masking is of peripheral origin, occurring lower down the perceptual hierarchy or relatively early on in the visual system processors; is energy dependent (i.e. the product of intensity and time); and obeys a multiplicative rule in which target energy x minimal ISI = a constant. In other words, masking is maximal when mask energy is greater than target energy at short ISIs, and the mask's effect decreases over longer ISIs. Also, forward masking was found to be more pronounced than backward masking, and its severity increased with increases in mask intensity whereas the severity of backward masking did not. In information processing terms, integrative or energy dependent masking occurs before iconic storage and consequently produces an unintelligible icon.

By contrast, Turvey demonstrated that interruptive masking is of central origin; is time dependent, sometimes being compared to a shift in attention; and operates according to an additive rule where target duration + minimal ISI = a constant. It is also relatively unaffected by stimulus energy, as long as that energy is within the range that is adequate for registration and recognition. Forward masking, in comparison to backward masking was found to be relatively weak and did not appear to follow the additive rule. The target duration plus critical ISI is equivalent to the SOA, so this empirically determined equation is consistent with the interruptive masking model of Sperling (1963) and Haber (1969), which argues that SOA limits the amount of time available for the central processing of the first stimulus. Again, in information processing terms, the TS forms a clear icon or representation but is disrupted by the mask on conversion to the categorical stage. Only global features of the input are present during iconic storage and no real analysis of the information is presumed to occur till the selection and categorical stage.

To summarise Turvey's model of masking, when two successive stimuli compete for the services of the peripheral system, the greater energy stimulus is dominant, whereas competing stimuli at the central decision processor will be chosen according to their order of arrival, with the most recent stimulus having the greatest effect.

The neurophysiological approach has been adopted by Breitmeyer and Ganz (1976), who have utilised the transient-sustained dichotomy in their theoretical explanation of visual masking. To account for both Type A and Type B forward and backward masking, they introduced two other mechanisms into their theory. The first involved lateral inhibitory activity within a given class of visual cells (i.e. intrachannel inhibition) and the second made use of inhibition between classes of visual cells (i.e. interchannel or transient-on-sustained inhibition).

According to Breitmeyer and Ganz, paracontrast, a Type B forward masking effect, occurs as a result of intrachannel inhibition. It is known that a visual receptive field's surround responds more slowly than its excitatory centre, and that the former inhibits the latter. Consequently, Breitmeyer and Ganz argued that at a critical SOA, the centre draws level with the surround, which results in masking. This phenomenon is assumed to occur both at the higher level of the striate cortex and lower down the visual hierarchy at the lateral geniculate nucleus (LGN), because evidence has shown that paracontrast can be obtained through the mechanism of intrachannel inhibition both monoptically by presenting the TS and MS to the same eye (Weisstein, 1972) and dichoptically by presenting the TS and MS to opposite eyes (Kolers & Rosner, 1960).

Further, Breitmeyer and Ganz (1976) proposed that only the sustained system is involved in paracontrast effects. The rationale for this is based on the finding of Fiorentini and Maffei (1970) that strong paracontrast effects are only obtained when both target and mask are modulated at low temporal frequencies, thereby activating predominantly sustained response channels and not transient channels.

Metacontrast, a Type B backward masking effect, on the other hand, is explained by interchannel inhibition, or the inhibition of the sustained response by the transient response. Breitmeyer and Ganz (1976) have assumed that interchannel inhibition is most effective both when the target and the mask activate the same preferred orientation of sustained and transient channels (decreasing in strength as their orientation preferences diverge), and when the inhibitory activity of transient channels is superimposed on the excitatory activity of sustained channels. As mentioned earlier, Type B masking usually portrays a U- or J-shaped function with maximum masking occuring at SOAs of between 50 and 100 msec. Also, it has been shown that cortical transient activity precedes sustained activity by 50 -100 msec or more (Dow, 1974, cited in Breitmeyer & Ganz, 1976). Therefore, according to interchannel inhibition, at this critical range of SOAs, cortical transient channels responding to the mask inhibit the activity of intermediate to high spatial frequency channels (i.e. sustained channels) activated by the target and so eliminate those spatial frequencies from the central processor. Breitmeyer and Ganz (1976) proposed that their interchannel inhibition hypothesis is equivalent to interruptive masking as suggested by Turvey (1973).

Forward and backward Type A masking is theorised to be an intrachannel inhibition mechanism. Breitmeyer and Ganz (1976) claim that due to the response persistence of sustained channels, integrative masking can occur at "peripheral iconic stores (ISp)" including retina and LGN and at "central iconic stores (ISc)" involving orientation-specific striate and post striate cortex. Peripheral masking by integration occurs when the target and mask compete for the same spatial frequency analyser channels. Here, the effectiveness of the mask is determined by the spatial frequency composition of the target and the mask and the time interval between them. Central masking by composite integration results from the synthesis of the target and mask's sustained responses. The extent to which the target and mask share this synthetic process bears an inverse relationship to the SOA.

Michaels and Turvey (1979) have since elaborated on the information processing approach to visual masking and challenged Breitmeyer and Ganz's (1976) suggestion that interchannel inhibition is equivalent to the interruptive hypothesis. They propose that the first few hundred milliseconds of visual activity can be dichotomised into two relatively distinct classes of operations: the icon synthesising stage performed by "a constructor" and the icon identification stage performed by "an algorist". Within this framework they postulate four distinct sources of masking; one peripheral and three central.

When visual fields are presented to the eye, Michaels and Turvey (1979) suggest that they are analysed by parallel and independent peripheral nets, each of which is sensitive to a certain range of spatial frequencies. There are two sets of peripheral nets, one for each eye. However, if two stimuli, for example a target and a mask, are presented monoptically within a certain temporal range, the same nets must be used. Consequently, the two stimuli combine within these peripheral nets and compete for their attention, with the most dominant stimulus, in terms of energy, becoming the successful one. This interaction is called "integration through within-net time-sharing" and can be equated with Breitmeyer and Ganz's (1976) peripheral masking by integration.

The function of the peripheral nets is to convey information to more central processes. The first of these is that of synthesis, whereby the brief, literal repesentation or icon of the visual display is formed from the output of the peripheral nets by the constructor. Michaels and Turvey (1979) suggest that their first source of central masking, which they call "integration through common synthesis" occurs at this stage of processing. At very brief intervals between target and mask presented dichoptically the two sets of properties overlap in time in the synthetic process. As a result, the ensuing iconic representation is made up of properties from both stimuli. Thus, when this iconic representation reaches the next stage of central processing, namely identification by the algorist, target information is poorly specified and performance is limited by the signal-to-noise ratio. Again, there are similarities between this concept and the notion of central masking by composite integration of Breitmeyer and Ganz (1976).

The second source of central masking, unlike the previous two mechanisms, can only operate in the backward masking paradigm. Through this masking interaction, known as interchannel inhibition, information from the target field is lost and, therefore, unavailable to the constructor for inclusion in the iconic composite. Like Breitmeyer and Ganz (1976), Michaels and Turvey (1979) hypothesise that at optimal SOAs, the slower sustained channels which carry form information about the target are inhibited by the transient response to the onset of the mask. However, whereas Breitmeyer and Ganz (1976) consider this interchannel inhibition to be a form of interruptive masking, claiming that the processing of the transient response to the mask interrupts the processing of the sustained response to the target; Michaels and Turvey (1979) view it as a form of integrative masking. Thus, according to Michaels and Turvey, when the algorist comes to identify the target, it is confronted with a combined representation of the two stimuli which excludes some of the spatial frequency information essential for target identification.

The third source of central masking (which also operates only in backward masking) occurs at the point of transfer of information to post iconic storage (the selection and categorical stage) because the algorist has insufficient time to process the target. At longer SOAs the constructor is able to provide an adequate representation of the target, unaffected by the following mask, for the algorist to identify. However, with the subsequent close arrival of the mask icon, processing of the earlier target ceases, and the attention of the algorist is redirected to this later-arriving representation. Michaels and Turvey (1979) refer to this interaction as the "replacement principle" because, while the information on the first field ostensibly remains available, it is "replaced" as the main object of algoristic attention. The explanation of interruptive masking is, therefore, the point at which the theories of these two pairs of researchers principally differ.

A further perspective on the integrative-interruptive dichotomy is proposed by Felsten and Wasserman (1980). They interpret the experimental data from various psychobiological and psychophysical studies as evidence of only one process in visual masking, namely, sensory integrative mechanisms, which lead to time dependent and energy dependent behaviour, depending on the stimulus conditions. Thus, Turvey's (1973) additive and multiplicative formulations are considered valid as rules for functional types of masking within the integrative paradigm under appropriate stimulus conditions, but not as distinctions between two different processes. Felsten and Wasserman also suggest that the backward mask, consistent with a sensory integrative model of masking, does not limit processing time, but rather limits the duration of the sensory signal representing the TS and the information-content of that signal. They, therefore, raise doubts as to whether processing on input that has already occurred is terminated.

3.3 VISUAL MASKING AND SPECIFIC READING DISABILITY

Within the framework of visual information processing, visual masking phenomena have been investigated in specific reading disabled children (SRDs) and normal readers to ascertain what perceptual deficits may occur at one or more processing stages. There is considerable evidence to show that SRDs do differ from controls in levels of masking (Blackwell, McIntyre & Murray, 1983; DiLollo et al, 1983; Lovegrove & Brown, 1978; Stanley & Hall, 1973) although this is not conclusive (Arnett & DiLollo, 1979; Fisher & Frankfurter, 1977). The general finding is that disabled readers require longer SOAs than normal readers to escape the effects of the mask. Since backward masking is said to provide an index of the rate of visual information processing (because a fast visual system will escape masking at a shorter ISI than a slower system) (DiLollo et al, 1983), this implies that SRDs process information more slowly and have a more limited capacity than normal readers.

As Sperling (1963), Haber (1969), and Turvey (1973) have proposed, the visual system can be assimilated to the information processing system. Information enters the system through a rapid decay storage unit known as the icon or visual information store (VIS). From here it is selected, encoded, and passed onto the short term memory (STM) store and with rehearsal may be transferred to long term memory (LTM). The VIS is considered to be primarily retinotopic and only represents information in a crude and global form. It is also very brief, lasting between 50 and 200 msec depending on the stimulus used.

Stanley and Hall (1973b) utilised a separation threshold and a backward masking paradigm as well as a temporal integration paradigm (which gives an index of the duration of visible persistence) to investigate the duration of the VIS in SRD and normal primary school children. In the backward masking experiment, subjects were required to identify letters made up of dots which were masked by a matrix of confusion dots. The stimulus and mask were presented at an initial ISI of 20 msec which was increased by 20 msec steps until a criterion of three correct letter identifications at a given ISI was reached. In the separation threshold and temporal integration experiment, subjects viewed pairs of stimuli presented in quick succession at varying ISIs until the criterion ISI at which the two parts of the display were first seen separately (separation threshold) and the criterion at which they were identified (integration) correctly on three successive occasions, were reached. The results showed that separation times of SRDs were 30 - 50 msec longer than those of normals and identification times both in the integration task and in the masking task were also significantly longer. Stanley and Hall interpreted the longer VIS duration as disadvantageous due to the consequent lag in the transformation of information to the STM store.

In an ealier non-masking experiment in which subjects were required to recall as many letters as they could from six letter displays presented at systematically lengthened exposure durations, Stanley and Hall (1973a) found that letters exposed for brief durations produced fewer correct responses in SRDs than normal readers, whereas at longer exposure durations their pattern of processing was the same as normals but took slightly longer. This was interpreted as evidence of differences in performance level attributable to a developmental lag in visual memory, not differences in kind of visual information processing.

Lovegrove and Brown (1978) also measured duration of VIS in SRDs and controls by means of a separation threshold technique and determined the rate of transfer from VIS to STM using a backward masking technique. Their results are consistent with those of Stanley and Hall (1973b) in that SRDs had significantly longer durations of VIS than controls and their information transfer rates were significantly slower. This was true for both age cohorts investigated (8- and 11-year-olds), but whereas the rate of transfer difference between the two groups increased with increasing age, the duration of VIS decreased with increasing age. Lovegrove and Brown (1978) interpreted this in terms of a developmental lag rather than a difference in the form of processing between the two groups, again supporting Stanley and Hall (1973a).

In a forced-choice letter recognition task where the matrix of noise letters was systematically increased, Blackwell et al (1983) replicated an earlier experiment (McIntyre, Murray, Cronin & Blackwell, 1978) in which learning disabled boys were found to have smaller spans of apprehension (i.e. the amount of information processed from a brief visual display) than normals, indicating an underlying deficiency in their central processing mechanisms which extract, analyse and encode information from brief visual displays. They then investigated the following three hypotheses regarding this finding for the learning disabled boys: (1) the noise letters may act as more potent distractors, (2) the decaying afterimage may fade more rapidly, and (3) the pick up of information may be slower. The results demonstrated that learning disabled boys were both more distractable and slower to pick up information than the controls.

Finally, DiLollo et al (1983), using similar methods to those of Stanley and Hall (1973b) confirmed their results in both the backward masking tasks and the separation threshold task, with slower rates of visual information processing and longer visible persistence durations in SRDs than controls. However, contrary to Stanley and Hall (1973b), the integration task revealed virtually identical durations of visible persistence between the two groups. DiLollo et al (1983) argue that the differing results for the two methods may be due to their different modes of retinal stimulation: the separation method over taxes the same retinal area whereas the integration method uses a single retinal location only once. They, therefore, suggest that SRDs may take longer to recover from the neural after-effects of stimulation than normals, and during this time the system may go into a refactory period during which no further information can be processed.

In opposition to the aforementioned studies, which found that SRDs have slower rates of visual information processing than normal readers, a study by Fisher and Frankfurter (1977) revealed that SRDs have faster processing rates. They used a letter identification and localisation task with and without backward masking and on all measures they found SRDs to be superior to normals. Also, there was less of a mask to no-mask performance difference in SRDs than normals, which according to Fisher and Frankfurter, contradicts the view of Stanley and Hall (1973) that longer VISs result in less efficient transfer of information from iconic too short term memory. They, therefore, conclude that a visual deficit hypothesis of SRD is inadequate.

Arnett and DiLollo (1979), on the other hand, failed to find any significant differences between the performance of SRDs and normal readers on both a temporal integration and a backward masking task. However, their lack of results could be explained in terms of insufficient differences between the two populations, since SRDs had a reading lag of only one year.

Thus, although the evidence is not without question, the greater proportion of these visual masking studies suggest slower rates of visual information processing in specific reading disabled children.

3.4 VISUAL MASKING AND INSPECTION TIME

The measurement of IT is typically carried out by a perceptual task involving backward masking and as such it is important to understand the operative nature of the visual masking process in this task. Little research has, as yet, been conducted with regard to masking in IT, but due to the methodological problem encountered in relation to the availability of apparent motion cues, a few studies are beginning to look at this issue.

The studies that do exist have attempted to establish the location of the mask, since the nature of the masking effect is held to depend upon the locus at which masking occurs, different loci representing different processes. The consistent finding has been that masking occurs centrally and is governed by Turvey's (1973) additive rule (Nettelbeck, Hirons & Wilson, 1984; Nettelbeck & Wilson, 1985; Turner, 1986; Longstreth et al, 1986), implying that the functional type of masking in the IT task is time dependent or interruptive, as was generally assumed.

Further, the Turner (1986) study demonstrated that, contrary to expectation, the difference in the efficacy of the mask between those who perceived apparent motion and those who did not, was not due to differences in its functional type. Both groups conformed to a time dependent (additive) rather than an energy dependent (multiplicative) model of masking. Thus, one hypothesised explanation for apparent motion cue use was ruled out.

The target and mask stimuli generally used in the IT task, such as the two-line, task result primarily in pattern or structure masking, but because the mask extends well beyond the target stimulus, metacontrast masking is also operative. It is from this use of metacontrast masking that the problem of apparent motion seems to arise, because there are strong similiarities between the stimulus conditions which produce metacontrast and those which produce apparent motion (Kahneman, 1968). Kahneman (1967) has suggested that at brief stimulus durations (less than 100 msec) both phenomena follow the same "onset-onset law", whereby the quality of apparent motion and metacontrast (with stimuli that are similar in energy and figural characteristics as in the two-line IT task) is determined by SOA, being optimal at SOAs of 100-120 msec.

In a later study which only considered the apparent motion aspect, Kahneman (Kahneman & Wolman, 1970) confirmed his onset-onset law and established an ISI law which states that for durations between 120 and 800 msec, apparent motion is optimal at an ISI of zero, that is, when SOA is equal to target duration. He also proposed that together these two laws express a single underlying rule " that the quality of motion depends solely on [the interresponsive interval] (IRI): the interval - or overlap - between the responses to the two stimuli at an unspecified level of visual analysis" (Kahneman & Wolman, 1970, p.163).

However, no light was shed on the mechanism of the phenomenon which codes this overlap into a percept of motion. Neither has any proposal been offered in the literature as to why some subjects perceive metacontrast and some apparent motion. It would appear that the distinction between these two groups in the IT task is based on individual differences in processing that go beyond the perception of apparent motion itself.

3.5 THE PRESENT STUDY

This study was part of a larger project designed to investigate the transient system deficit in SRDs aged 12 and 13. The project offered an opportunity to take advantage of a nonretarded IQ sample much greater than has been used hitherto, as well as a selected group of SRDs, all belonging to a specific age cohort. The availability of such a subject sample provided several aspects of investigation for this inspection time study.

1. It afforded the possibility of confirming two findings that have been evidenced in previous research with normal subjects.
   (a) First, there is the relationship between inspection time and IQ. Although the evidence for such a relationship is somewhat equivocal in child studies (Doyle, 1986; Hulme & Turnbull, 1983; Irwin, 1984; Ridgers, 1986; Smith & Stanley, 1983), on the basis of the significant correlation reported in Doyle's (1986) study with a sample of 12-year-old nonretarded subjects, it was hypothesised that a relationship between IT and IQ would exist.
   (b) Second, there is the distinction between those subjects who make use of apparent motion cues and those who do not. Mackenzie and Bingham (1985) and Mackenzie and Cumming (1986) have shown that a fairly consistent proportion of adult subjects use apparent motion cues, and that this cue use reduces the relationship of IT with IQ to a nonsignificant level. Doyle (1986) later confirmed this finding in a normal 12-year-old sample, despite an attempt to devise stimuli which would minimise such cues. It is, therefore, hypothesised that similar groups of apparent motion strategy users and non-users will be found among the control group, together with a reduction in the IT-IQ association among strategy users. However, it remains to be seen whether a relationship exists between cue usage and specific reading disability.
2. It enabled the experimenters to test for mean differences in inspection time between SRDs and normal readers. Evidence has shown that SRDs both suffer from a transient system deficit and have a slower rate of visual information processing than normal readers. In their speculation on the role of a deficient transient system in the reading process, Lovegrove and his colleagues (1986; Slaghuis & Lovegrove, 1984)

have suggested that the slower rate of visual information processing found in SRDs may be due indirectly to their poorly functioning transient mechanisms. However, if this is not the case and the slower rate of visual information processing is attributable to some other cause, for example, a developmental lag in visual memory (Stanley & Hall, 1973a), it is possible to make two separate predictions with regard to the likely performance of SRDs on an IT task, based on the evidence from these two theoretical perspectives (namely, the psychophysical/neurophysiological and information processing approaches).

On the one hand, a transient system deficit would suggest that the transient signal of the mask would be weak and being weak would travel more slowly to the central processor. For both these reasons masking would be less effective for SRDs than controls. To produce the same masking effect for both groups the SOA of SRDs would have to be shortened. Therefore, it can be hypothesised that the ITs of SRDs will be shorter than those of controls.

On the other hand, a slower rate of visual information processing generally would suggest that SRDs require longer exposure durations to apprehend the same amount of information as controls. This would make SRDs more vulnerable to interruption by masking on the IT task, and necessitate longer ITs to evade the mask. One study, which investigated this issue, did indeed find that the ITs of dyslexics were significantly longer than those of controls, although there are a number of methodological problems with this study (Whyte, Curry & Hale, 1985). Therefore, it can be hypothesised that the inspection times of SRDs will be longer than those of controls. The direction of the difference in mean IT between normal readers and SRDs (assuming that a difference is found) would therefore clarify the processing differences between the two groups.

3. Finally, and most importantly, it was possible to ascertain whether there is a differential correlation in the relationship between IT and IQ measures on the WISC-R (particularly PIQ) for controls and SRDs, in an attempt to further understand what it is that IT measures. Assuming that an IT-IQ relationship is found and that the mean ITs of SRDs are significantly different from (either longer or shorter) than those of controls, it is further hypothesised that there will be less correlation between IT and IQ in SRDs than in normal readers. The rationale is as follows:

In the case of the transient deficit hypothesis, if there is a differential functioning of the transient system in SRDs and controls, as well as a differential relationship between IT and IQ in these two groups, it will provide strong evidence that the transient sytem is implicated in the relationship between IT and IQ. In other words, if in SRDs there is a disruption of the mechanism whereby information enters the doors of perception, where it can be further processed, and if IT is correlated with IQ because of being a measure of the speed at which information passes through these doors, it follows that in SRDs the relationship between speed of input access and IQ will be disrupted.

In the case of the rate of visual information processing hypothesis, a similar rationale would apply, with the slower rate of visual information processing impeding the speed of uptake of information in the visual IT task. Thus, if there is a differential rate of visual information processing in SRDs and controls, as well as a differential relationship between IT and IQ in these two groups, there will be reason to suggest that rate of information processing is involved in the relationship between IT and IQ.

It is anticipated that if a differential correlation between these two measures does exist, it will be more marked in PIQ than VIQ. The reason for this is that the VIQ scores of SRDs are likely to be lower than those of normals, whereas PIQ scores are expected to be about the same.

CHAPTER 4

METHOD

4.1 SUBJECTS

One hundred and fifty five (92 male and 63 female) Grade 7 students from four state high schools in Hobart took part in this experiment. Their average age was 12 years 11 months (range 12 years 3 months to 13 years 11 months). The selection of subjects was based on criteria designed for the major project and was carried out in two stages. At the initial screening stage, subjects were selected on the basis of their group intelligence quotient (IQ) using the Standard Progressive Matrices (SPM) (Raven,1938) and their group reading quotient (RQ) using either the Schonell R4 Reading Test (R4) (Schonell, 1944) or the Tasmanian Word Knowledge Test (TWK) (Davidson, unpublished), all of which were administered by the schools' Guidance Officers. The criteria for inclusion were that all subjects should have IQs equal to or greater than 90, and that the control group (normal readers) should have RQs which were not more than 8 points below their IQs, while the experimental group (poor readers or SRDs) should have RQs which were 15 points or more below their IQs.

These subjects were then assessed individually for their IQ level on the revised Wechsler Intelligence Scale for Children (WISC-R) (Wechsler, 1974), for their RQ level on the Neale Analysis of Reading Ability (Neale, 1966), and for their score on a nonsense word (NW) test compiled especially for the assessment of SRDs (Martin, 1986). Two samples were constructed on the following criteria: that SRDs have a reading age two years below that of their chronological age, according to accuracy on the Neale reading test, and a score of less than 30 on the NW test, and that controls have a reading age less than one year below that of their chronological age or equal to or greater than 12, plus a score above 34 on the NW test. Students whose poor reading ability was the result of known causes such as brain damage, having only recently acquired English as a second language, or having language retardation due to deafness were excluded. The resultant samples consisted of 65 normal readers (controls), 24 clearly defined SRDs, 23 poor readers (who were not SRDs on the basis of the NW test), and 43 others (who fell into none of the former categories).

The students had been previously screened for visual acuity by the School Medical Service (Snellen eye chart) and all subjects had normal or corrected to normal vision. Signed consent forms were obtained from the parents of each participant.

4.2 APPARATUS, MATERIALS, AND STIMULI

4.2.1 Intelligence Tests

The Raven's Standard Progressive Matrices (Raven, 1938) and the Wechsler Intelligence Test for Children - Revised (Wechsler, 1974) were used as indices of intelligence.

4.2.2 Reading Tests

The Neale Analysis of Reading Ability (Neale, 1966), and the nonsense word test (Martin, 1986) were used to assess competence in reading.

4.2.3 Inspection Time Task

The Inspection Time programme developed by Dr Brian Mackenzie and previously used at the University of Tasmania was run on an Apple II+ microcomputer equipped for running Pascal programmes. Stimuli were displayed on a 30 cm black and white video monitor. To control for the wide variability in lighting conditions of the rooms made available in the four different schools, the programme was run in the semi-dark with an average space luminance of less than 1 foot lambert. Stimulus luminance was then maintained at approximately 9.5 foot lambert to ensure that the stimulus could be seen comfortably. Screen luminance was less than 0.5 foot lambert and therefore the contrast was greater than 0.9. Although these levels of luminance are lower than in some previous experiments (e.g. Mackenzie & Bingham, 1985, cf Mackenzie & Cumming, 1986), Turner (1986) has shown that manipulation of target stimulus brightness does not affect the inspection time (IT) measure.

Target stimuli were two horizontal, parallel lines 40 and 60 mm long with a vertical separation of 17 mm. The mask was composed of two 140 mm lines which covered the target lines. The location of stimuli on the screen was constant over trials, with the difference between the length of the lines always appearing on the right. Two small dots in the centre of the screen, where the target stimuli would appear, acted as an attentional cue and a signal for the subject to commence the next trial.

Subjects were seated approximately 75 cm from the monitor screen so that the shorter and longer stimulus lines subtended visual angles of around 3.1 ° and 4.6 °, respectively. Duration of stimulus exposure was controlled by a software loop in the inspection time programme, and stimulus presentation was synchronised with frame onset to enable exact timing.

Two instruction sheets were drawn up for the use of the five experimenters involved in the inspection time task, to ensure that a standard procedure was followed. The first instruction sheet outlined the practical steps to be taken in setting up and running the experimental task for each individual subject, as well as those for giving the apparent motion cue questionnaire (Appendix A). The second sheet contained the subject's instructions which were to be read out to the subject by the experimenter (Appendix B).

4.2.4 Apparent Motion Cue Questionnaire

A simple questionnaire (Appendix C) appropriate to the age level of the students was devised to ascertain whether they made use of apparent motion cues to discriminate between the stimuli. The first question was open ended (How did you tell which line was longer when they were coming really fast?) giving subjects the freedom to volunteer information on the use of any strategies. The second and third questions (Did you see the lines seem to move? and Did that help you tell which was longer?) were more direct and closed, and were followed by the prompt "How?" if the answer was affirmative.

4.3 PROCEDURE

4.3.1 Intelligence and Reading Tests

The SPM, WISC-R, R4, TWK, and Neale were administered by the Guidance Officers of the four schools, whereas the NW test was given by the project experimenters. Scores on the SPM and R4 or TWK were obtained for the purposes of sample selection prior to the running of the inspection time task, but the WISC-R, the Neale and the NW test were given during the experimental period. Some subjects were absent from school at vital times. Consequently, data is missing on a number of these measures (see Appendix D).

4.3.2 Inspection Time

The organisation of the major project demanded that the author of this study take part in conducting all the experimental tasks with the four other project experimenters, including the inspection time task. Therefore, a training session was held for these four experimenters by the author of this study, to familiarise them with the standard procedure outlined in the two instruction sheets (Appendices A and B)

Subjects were tested individually. The experimenter explained the task to each subject using the subject instruction sheet (Appendix B). Subjects were instructed to decide whether the longer line in the target figure was at the top or the bottom and then to press the corresponding response key. Trial onset was under the control of the subjects (by pressing either button on the response panel). At the beginning of each trial two dots appeared in the centre of the screen to focus attention on where the target would appear and a message at the top of the screen read "PRESS EITHER BUTTON WHEN READY AND WATCH THE PLACE WHERE THE DOTS ARE NOW". When the subject pressed either button, the dots disappeared and one second later were replaced by the target stimuli. After the stimuli had been displayed for the designated exposure time, they were covered by the mask, and the subject pressed the appropriate button. A response terminated a trial, bringing the message and the two dots back to the screen.

Subjects were encouraged to avoid errors, and the importance of accuracy rather than speed of responding was stressed. To assist concentration and maximise accurate responding within the limits of subjects' ability to discriminate, a feedback mechanism was incorporated into the computer programme, producing different tones if the response was correct or incorrect. Subjects were also informed that the task would become progressively more difficult, until it was almost impossible to detect which line was longer because the target stimulus would be covered over so quickly. However, on these occasions they were to guess.

In addition, if a subject was momentarily inattentive and missed a target, a trial could be aborted by pressing the space bar on the computer keyboard once or twice. This technique was carefully monitored by the experimenter, to ensure that it was only used in cases of genuine inattention. The experimenter was seated to the left of the subject throughout the task, both to answer questions and clarify the procedure during the initial set of trials (practice), and to encourage the subject to pay attention before each trial.

Every subject completed two blocks of inspection time trials, each of which was presented in two separate sections, resulting in four sets of trials altogether. The first section of each trial block both served as a practice set for the subject and determined the target stimulus duration which would be used at the start of the second section. The calculation of the IT measure was made entirely on the basis of this second section of each block of trials. Inspection times were measured by a computer-controlled adaptive staircase procedure (Wetherill & Levitt, 1965) used in the studies of Mackenzie and Bingham (1985) and Mackenzie and Cumming (1986), which increased the exposure duration following an incorrect response and decreased it after a criterion number of correct responses depending on the level of accuracy required. The criterion used in the staircase for the second section of each block of trials was three correct responses, which yielded a threshold of an accuracy level of 79.4%. The relative position of the longer line (top or bottom) was varied randomly across trials.

A brief interval occurred between the two sets of trials in each block while the automatically recorded responses were saved on the computer disc, and a longer rest period was given to the subjects between blocks while the programme was re-run. In all, the task took about 20 minutes, depending on response latency and overall consistency in responding.

4.3.3 Apparent Motion Cue Use

At the end of the inspection time task, the experimenter completed an apparent motion cue questionnaire (Appendix C) for each subject by asking him/her the three questions (unless a negative response to question two did not warrant further questioning) and recording his/her verbatim replies in the spaces provided. The experimenter also recorded her own judgement as to whether the subject was using an apparent motion cue or not. Later subjects were categorised as cue users or non-users on the basis of their replies to these questions by the main experimenter.

4.3.4 Data Analysis

The data to be analysed were the IT measures and the IQ measures, and the use or non-use of apparent motion cues, for both SRDs and controls.

The relationship between IT and IQ measures was assessed by product-moment correlations computed in the whole sample and in the subsamples of both SRDs and controls, and of cue users and non-users. Differences between subsamples in the strength of the relationship, and in the mean IT scores, were analysed by appropriate t tests.

CHAPTER 5

RESULTS

5.1 INSPECTION TIME

5.1.1 Total Sample

Inspection time measures, shown in Table 1, were calculated for all subjects on both blocks of trials together with the mean of these two measures.

Table 1: Means and standard deviations (SD) of inspection time measures in milliseconds for the total sample (N = 155).

	MEAN	SD
IT1	108	92
IT2	92	63
Mean (1+2)	100	75

It was decided to take the mean of the two inspection time measures as the overall estimate of inspection time (IT) for use in all correlational analyses. So, henceforth, any mention of the IT measure will refer to this mean. The estimated reliability of IT was .89 (Cronbach's A, cited in Nunnally, 1967), which compares favourably with the test re-test reliabilities in Table 4 of Nettlebeck (in press).

5.1.2 Matched Sample

The SRD sample of 24 subjects was matched on IQ, using the SPM scores, with 24 controls from the sample of normal readers, to ascertain whether the inspection times of the SRDs were shorter or longer. The mean SPM score for both groups was 105. The means and standard deviations (SD) of IT and SPM scores for the matched sample of SRDs and controls are shown in Table 2. Alhough the mean IT for SRDs is longer than that for controls, this difference is not significant ($t\ (46) = 0.33$, n.s.).

Thus, the hypothesis that SRDs would have shorter ITs than controls, on the grounds that they have a deficient transient system which enables them to evade the mask, is not confirmed. Neither is the alternative hypothesis confirmed, namely that ITs of SRDs would be longer than those of controls, due to SRDs' slower rates of visual information processing.

Table 2: Means and standard deviations (SD) of IT in milliseconds and SPM scores for the matched sample of SRDs and controls (n = 48).

	IT (msec)		SPM	
	MEAN	SD	MEAN	SD
SRDs	119	80	105	9.6
CONTROLS	110	106	105	8.4

$t\ (46) = 0.33$, $p > .1$, one-tailed

5.2 INSPECTION TIME AND MEASURED INTELLIGENCE

Unfortunately, a large number of testers (more than 12) administered the WISC-R and some of the testing was conducted in rushed conditions. As a result the procedures for testing were poorly standardised, and this is reflected in the correlations among the subtests. Whereas the data on the SPM were consistent with previous research, the WISC-R data were very puzzling. Some decrease in internal consistency is appropriate for a sample including SRDs, but when corrected for contamination the correlations remained disparate. Consequently, a factor analysis was conducted on both the data of this study, using the normal reader subsample, and the standardised data in the WISC-R Manual. The proportion of variance accounted for by the first principle component in the FSIQ (35.7%), VIQ (50%), and PIQ (41.7%) was found to be considerably lower in this study's normal reader sample than in the standardised sample (50.7%, 61.1%, and 54.9%, respectively). The low commonality of the subtests in this study, thus, bore out the impression that the administration of the tests was not adequately standardised. For this reason the WISC-R data have been disregarded, but are included in the Appendix (E) for reference. The presentation and discussion of the results will now focus on the Standard Progressive Matrices.

5.2.1 Total Sample

Mean IQ on the SPM for the total sample was 109 with a standard deviation of 9.9. The correlation between IT and SPM for the total sample, shown in Table 3, is significant at the .01 level, but the association is small. Therefore, the existence of a weak relationship between IT and IQ for this age group can be said to be confirmed. However, when the disabled readers and uncategorised subjects were excluded (see Normal Readers in Table 3), this correlation falls to nonsignificance ($r = -.19$, n.s.), indicating a similar pattern to that found in the IT-IQ correlations of mixed samples of retarded and nonretarded subjects, when retarded subjects are excluded.

Table 3: Correlations between IT and SPM scores for the total sample and each subsample.

		SPM
All Subjects	(N = 155)	-.30 **
Normal Readers	(n = 65)	-.19
SRDs	(n = 24)	-.39
Matched Controls	(n = 24)	.10

** $p < .01$, two-tailed

5.2.2 Matched Sample

Correlations between IT and SPM for the matched sample are presented in Table 3. The IT-IQ correlation for SRDs just falls short of significance at the .05 level ($r = -.39$, $p < .06$), whereas that for controls is not significant and shows a positive trend ($r = .10$, n.s.). The difference between these two correlations approaches significance ($z = 1.65$, $p < .1$, two-tailed), and contrary to expectation the correlation for SRDs is higher than the correlation for the matched controls. Therefore, the hypothesis that there would be less correlation between IT and IQ in SRDs than in normal readers is not confirmed.

5.3 APPARENT MOTION CUE USE

Subjects were divided into cue users and non-users according to the following criteria. Users included those who gave a description of apparent motion in answer to Question 1 (How did you tell which line was longer when they were coming really fast?) and/or Question 2 (Did you see the lines move?). However, subjects were not included as users, despite answering "Yes" to Question 2, if they were unable to describe apparent motion at all. This was to eliminate "Yes" answers due solely to demand characteristics. Non-users were those who did not describe apparent motion in Question 1 and who gave a negative answer to Question 2. Question 3 gave little further information than was already provided by the first two questions, apart from a more detailed description of apparent motion, and so this question was not used in the assignment of categories.

5.3.1 Total Sample

Table 4 presents the means and standard deviations for the SPM and IT for cue users and non-users in the total and normal samples together with the sample sizes.

Table 4: Mean IT (msec) and SPM scores for users and non-users of apparent motion cues for the total sample (N = 155) and the normal sample (n = 65).

			IT (msec)		SPM	
		n	$\bar{X}$	SD	$\bar{X}$	SD
Total Sample	Users	127	92	41.8	109	9.8
	Non-users	28	138	148.4	112	10.2
Normal Readers	Users	51	76	33.9	112	10.7
	Non-users	14	127	132.6	116	7.6

Cue users greatly outnumber non-users in both the total sample and the normal sample, contrary to the findings of previous adult (Mackenzie & Bingham, 1985; Mackenzie & Cumming, 1986) and child (Doyle, 1986) studies. Therefore, the hypothesis that similar groups of apparent motion strategy users and non-users would be found among the control group is at best partially confirmed.

The ITs of nonusers were significantly longer than those of users in both samples ($t(153) = 3.02$, $p < .01$, two-tailed; $t(63) = 2.5$, $p < .02$, two-tailed) and considerably more variable ($F(27,126) = 12.6$, $p < .02$; $F(13,50) = 15.3$, $p < .02$). However, there is no significant difference between cue users and non-users on SPM scores (although those of non-users tend to be higher) which shows that strategy use is not related to intelligence.

Correlations between IT and SPM for cue users and non-users in the total and normal samples are shown in Table 5. As predicted, the correlation for non-users in the total sample is significantly higher than that for cue users, but nevertheless the latter correlation itself remains significant. The difference is in the same direction in the (much smaller) sample of normal readers, but does not approach significance.

Table 5: Correlations between IT and SPM scores for users and non-users of apparent motion cues in the total sample (N = 155) and the normal sample (n = 65).

	SPM		Z^a
	Cue Users	Cue Non-users	
All Subjects	-.25 *	-.60 ***	2.02 *
	(n = 127)	(n = 28)	
Normal Readers	-.28 *	-.44	0.54
	(n = 51)	(n = 14)	

[a] test for significance of difference between users and non-users.

*p <.05, *** p <.001, two-tailed

5.3.2 Matched Sample

Among the SRDs there were 20 cue users and only 4 non-users, and in matched controls there were 22 cue users and only 2 non-users. Therefore, SRDs are as likely as controls to make use of apparent motion cues ($X^2 1$) = 0.19, n.s., Yates correction).

CHAPTER 6

DISCUSSION

6.1 A DIFFERENTIAL IT-IQ RELATIONSHIP IN SRDs AND NORMAL READERS

The main hypotheses of this study were that the ITs of SRDs would be shorter or longer than those of normal readers depending on the type of dysfunction operating in SRDs. On the one hand, it was predicted that a deficient transient mechanism would produce a weak transient masking signal which would travel more slowly to the central processor, so that SRDs would experience less masking and be able to evade the mask earlier than controls; this would result in shorter ITs. On the other hand, it was predicted that a slower rate of visual information processing would necessitate that SRDs use longer exposure durations to gain the same amount of information as controls, thereby causing them to evade the mask later; this would result in longer ITs. Neither of these hypotheses was confirmed. Specific reading disabled students, who, according to the research literature, should have the above-mentioned deficits, performed as well as normal readers on the IT task.

At least two interpretations may be made of these results. One interpretation is that the SRDs in this study were not drawn from the same population as those employed in the transient deficit and visual masking studies; although this is unlikely, because similar stringent criteria were used for their selection, which eliminated the merely poor readers. Alternatively and more probably, it may be concluded that low level perceptual deficits, and by implication the mechanisms underlying these deficits, are not related to inspection time.

The finding in this study is not consistent with the results of Whyte and her colleagues (1985) who found that the ITs of SRDs were significantly longer than those of controls. However, there are a number of methodological problems in the Whyte et al study which reduce its value. As reported, the IT task itself is quite different from the established IT task used in this study. Their target stimulus was two white lines on a black background 30 mm and 31mm in length and 10 mm apart with a horizontal line of 30 mm terminating the upper ends, and their backward mask consisted of a random pattern of lines. Consequently, discrimination was made on the basis of a single millimetre difference between the two lines, making the task a fine discrimination task involving central foveal vision. Secondly, in the staircase procedure adopted by Whyte et al, the target stimulus duration was increased by one step (20 msec) for each correct response, giving only a 50% accuracy level. Thirdly, the reading age of their disabled readers was only one year below their chronological age, so that their SRDs may represent a different population from that investigated here. Fourthly, the sample size was very small, with only 7 SRDs and 7 controls. Further, the mean IT of the SRD group decreased with the increase in the number of trials, as did the variability, suggesting that the SRDs took longer to settle down to the task than the controls and that, with sufficient practice, their performance may more closely match that of normal readers.

Due to the fact that the main hypotheses were not confirmed, there was no basis on which to predict less correlation between IT and IQ in SRDs than in normal readers, and indeed a smaller IT-IQ association was not found. Thus, again there was no evidence to implicate the transient system or slower information processing rates in the relationship between IT and IQ. On the contrary, there was a trend for the IT-IQ correlation of SRDs to be higher than the correlation of the matched controls ($z = 1.65$, $p < .1$, two-tailed). This trend has been replicated in further research (Mackenzie, 1987, personal communication) with a larger subject sample (approximately 50 SRDs), producing a larger trend which is probably significant. Unfortunately, the SRD sample in this study was smaller than anticipated due to the major project's initial selection criteria which included a number of poor readers and unclassified subjects. Nevertheless, the difference between the IT-IQ correlations of the two groups is marginally significant.

The interesting finding of a higher IT-IQ association in the reading impaired poses a theoretical puzzle. It is possible that the reason for the elevated IT-IQ correlation in SRDs is that IT is indexing degree of perceptual deficit rather than intelligence. If this speculation is true, one would expect that there would be significant correlations between other measures of perceptual deficit and inspection time. Flicker and visible persistence measures were obtained in the larger project conducted concurrently with this study, but IT was not shown to correlate significantly with either measure. However, it was considered that there were some inadequacies in these measures, so future research may yet support this speculation.

Nevertheless, the anomalous findings of this study present a real paradox, which is extremely perplexing. On the one hand, the lack of a significant difference between the mean ITs of SRDs and controls indicates that low level perceptual deficits are not related to IT, but on the other hand, a differential IT-IQ relationship suggests that they are. Further research may help to unravel this paradox and provide a solution to the puzzle.

6.2 THE OVERALL IT-IQ RELATIONSHIP

A significant correlation, though small ($r = -.30$, $p < .01$) was found between IT and IQ on the SPM for the total sample, which confirms the general hypothesis for the existence of an IT-IQ relationship. This result is consistent with the finding of a small but significant correlation both between IT and general ability in Irwin's (1984) study with a 12-year-old sample (although Irwin's data have been criticised on account of the large means and standard deviations and the marked skewness of the distribution) and between IT and Performance IQ in Hulme and Turnbull's (1983) study using 6- and 7-year-olds as subjects. On the other hand, it does not match the high correlations found in Doyle's (1986) study, which was conducted at the same time, using the same procedure. An explanation for this may be given in terms of the use of apparent motion cues. Whereas

82% of all the subjects in this study used apparent motion cues, only 42% were cue users in Doyle's study. Since it is known that cue use reduces the IT-IQ correlation, it is possible that this study's overall IT-IQ correlation (as well as the IT-IQ correlations of each subsample) was influenced by the unusually high proportion of cue users. This suggestion is borne out by the high correlation ($r = -.6$, $p < .001$, two-tailed) found in the non-users.

However, whereas a significant IT-IQ correlation exists for the total sample, when the disabled readers and the uncategorised subjects are excluded, the correlation falls to nonsignificance. A similar pattern has been found in the IT-IQ correlations of mixed samples of retarded and nonretarded subjects, when the retarded subjects are excluded (Anderson, 1977, cited in Brand, 1981; Deary, 1980, cited in Brand & Deary, 1982; Grieve, 1979, cited in Brand, 1981; Hartnoll, 1978, cited in Brand, 1981; Nettelbeck, 1982). This finding has led Vernon (1983) to suggest that IT is a threshold variable which can distinguish between extreme samples such as retarded and nonretarded subjects, but not within homogeneous groups of average or above-average intelligence, although the IT-IQ association is fairly robust within retarded samples. Why this is so has not yet been shown, neither is it clear why such a phenomenon should occur in a mixed sample of SRDs and normal readers, whose IQs are distributed across the same average to above-average range.

While there is no analogous reason for this similar finding in mixed samples of retarded and nonretarded subjects, and SRDs and normal readers, one common facet which they share is erratic eye movements (Nettelbeck et al, 1984; Rayner, 1978; Slaghuis & Lovegrove, 1985) and this may be worth investigating. As suggested earlier, it may be that IT is measuring degree of visual dysfunction, but further research is needed to clarify this suggesttion.

6.3 APPARENT MOTION CUE USE

The finding of a significant difference between the IT-IQ correlations of cue users and non-users in the total sample, with non-users demonstrating a higher IT-IQ association confirms previous findings that cue use reduces the IT-IQ relationship (Doyle, 1986; Mackenzie & Bingham, 1985; Mackenzie & Cumming, 1987). Also, the difference between the IT-IQ correlations of cue users and non-users among the normal readers is in the same direction, although it is not robust enough to be significant. However, no relationship was found between cue usage and specific reading disability. If SRDs had been found to be less likely than their matched controls to use apparent motion cues, this would have offered an explanation for their higher IT-IQ association; but, on the contrary, they obtained this correlation while actually using apparent motion cues.

The proportion of cue users is much higher in this study than in earlier studies (82% compared to 42% in Doyle's (1986), 55% in Mackenzie & Bingham's (1985), and

59% in Mackenzie & Cumming's (1986) study). This suggests that for some reason apparent motion cues were more available to all subjects, so that any differences that may have emerged between the two groups could have been hidden. The greater availability of cues may have been due to a methodological problem with regard to the luminance conditions in the experimental rooms or the contrast on the computer screen, although Turner's (1986) study has shown that the IT measure is not affected by the brightness of the stimuli.

6.4. CONCLUSION

There are no significant differences between SRDs and normal readers on the IT task in the length of inspection time, IT-IQ correlation, or apparent motion cue use. Therefore, low level perceptual deficits, such as are implicated in specific reading disability, would appear not to be involved in inspection time. This, however, leads to the paradox of how there can be a higher IT-IQ correlation (which is marginally significant and which has been replicated) in SRDs than normal readers, if what it is that makes them SRDs has no relation to inspection time. Further research is needed to resolve this anomaly.

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APPENDICES

APPENDIX A

INSTRUCTIONS FOR EXPERIMENTER

1. Place SRD Version of Inspection Time in drive 1.

2. Place Inspection Time data disc in drive 2.

3. Boot disc and press "L" to load SRD Version.

4. Check that the video sync switch is down, that the computer is switched to 40 column, that the button board is plugged in, in the correct order, as follows:

Back	Nothing		4	Ground
	Green	3	0	
	Red	2	1	
Screen	Black	1	2	

   and that the student is sitting approximately 75 cm from the screen.

5. Type File Name for Results i.e. the subject's number, initial, and surname, plus the date and 1 denoting the FIRST RUN e.g. S1.K.LLOYD.21 AUG.1.

6. Go through the standardised instructions with the subject.

7. Commence the FIRST set of trials (PRACTICE), making sure that the subject is pressing the correct button for the LONGEST line. Correct the subject if necessary at this stage.

8. Ensure that the subject keeps his/her eyes on the screen and ONLY presses EITHER button to change the stimulus when the two dots are visible in the centre of the screen.

9. Wait for the FIRST set of trials to be SAVED. Then run the second set of trials without assisting the subject.

10. Wait for the SECOND set of trials to be SAVED. Then type "RUN" RETURN. Type the same File Name except for replacing the 1 with a 2, denoting the SECOND RUN e.g. S1.K.LLOYD.21.AUG.2., and let the same subject complete both sets of trials again on his/her own. (Each subject completes 4 in all, arranged in 2 runs or blocks).

11. Complete the QUESTIONNAIRE SHEET with each subject, recording their number, names, and verbatim replies in the spaces provided.

N.B. If you need to abort at any time press CONTROL RESET and then type RUN.

Contrast and brightness must be re-calibrated at each new school.

APPENDIX B

INSTRUCTIONS FOR SUBJECT

1. Hold the button panel vertically with the RED button at the TOP and the GREEN button at the BOTTOM.

2. When you see the 2 dots in the centre of the screen, press either button to change the picture.

3. TWO lines will appear on the screen. One will be longer than the other. They will appear very quickly, then they will be covered up. You must decide which line is the LONGEST. If the TOP line is the LONGEST, press the TOP button. If the BOTTOM line is the LONGEST, press the BOTTOM button.

4. The lines will then disappear. If you pressed the RIGHT button, the computer will BLEEP. If you pressed the WRONG button, the computer will BLUBBER. Then the 2 dots will return.

5. When you see the 2 dots in the centre of the screen, press either button to change the picture.

6. The task will become more and more difficult, but its more important to get it right than to go fast. If you cannot tell which line is longer, then GUESS.
   (N.B. A trial can be aborted <u>before</u> pressing a button, by pressing the space bar once or twice. Therefore, if a student misses a target through inattention, this procedure can be explained to him/her. <u>However</u>, this technique should not be overused.)

7. Continue in this way until the FIRST set of trials is completed, wait, then complete the SECOND set of trials.

8. Do you have any questions?

9. Remember to concentrate on the screen.

APPENDIX C

INSPECTION TIME QUESTIONNAIRE

SUBJECT'S NUMBER..............................DATE...........................

SUBJECT'S NAME..

1. How did you tell which line was longer when they were coming really fast?

2. Did you see the lines seem to move?
(Prompt with "How?", if necessary).

3. Did that help you tell which was longer?
(Prompt with "How?", if necessary).

EXPERIMENTER'S NAME ....

Judgement of use of apparent motion cue YES

NO

? ? ?

APPENDIX D

SUMMARY OF SUBJECT DETAILS AND SCORES ON EACH DEPENDENT VARIABLE FOR ALL SUBJECTS (N=155)

<u>CODE</u>

Subj	Subject		S	Similarities	SPM	Standard Progressive Matrices
	No's 1 - 65	Normal Readers	A	Arithmetic	NAcc	Neale Accuracy
	No's 1 - 24	Matched Controls	V	Vocabulary	NW	Nonsense Word test
	No's 66- 89	SRDs	C	Comprehension	IT1	Inspection Time (Block 1, 2nd set).
	No's 90-112	Poor Readers	DS	Digit Span	IT2	Inspection Time (Block 2, 2nd set).
	No's 113-155	Others	PC	Picture Completion	IT	Inspection Time (Mean of 1 and 2).
VIQ	Verbal IQ		PA	Picture Arrangement	Cue	Apparent motion cue use
PIQ	Performance IQ		BD	Block Design	Y	Yes
FSIQ	Full Scale IQ		OA	Object Assembly	N	No
I	Information		COD	Coding	M	Marginal

Subj	Sex	Age	VIQ	PIQ	FSIQ	I	S	A	V	C	DS	PC	PA	BD	OA	COD	SPM	NAcc	NW	IT1	IT2	IT	Cue
1	M	12.58	103	118	111	11	11	8	11	12	12	15	8	14	13	13	107	12.70	36	640	507	574	N
2	M	13.50	102	92	97	11	11	10	11	9	7	8	9	11	10	7	92	12.70	39	82	80	81	Y
3	M	12.25	117	111	116	12	14	10	11	17	13	9	11	15	12	11	107	11.90	38	140	72	106	Y
4	F	12.58	102	95	99	10	13	9	10	10	7	10	7	9	11	10	101	12.30	35	100	82	91	Y
5	F	12.58	119	130	127	11	13	12	16	14	10	12	10	13	17	19	126	12.70	39	172	130	151	Y
6	M	13.00	100	105	102	9	11	9	10	11	11	10	11	12	11	10	105	12.10	38	102	100	101	Y
7	M	12.58	113	114	115	12	13	14	13	9	7	11	9	14	13	14	101	12.30	40	72	47	60	Y
8	M	13.75	111	101	106	14	11	10	12	12	9	9	12	12	10	8	98	12.70	37	65	82	74	Y
9	M	13.16	109	106	109	11	12	11	12	12	11	13	11	11	8	12	92	12.20	40	97	90	94	Y
10	M	12.83	113	124	121	11	11	14	14	11	9	10	15	13	13	16	101	12.50	39	75	70	73	Y
11	M	12.67	119	108	116	14	14	8	14	16	8	15	11	10	10	10	109	12.70	40	65	72	69	Y
12	M	12.33	109	112	112	11	12	8	4	13	9	14	11	12	12	10	107	12.40	40	212	172	192	Y
13	M	12.42	112	104	109	14	10	10	16	10	12	8	10	13	13	9	124	13.00	38	72	45	59	Y
14	F	12.67	95	114	103	10	9	10	8	9	11	12	13	12	10	13	104	12.30	36	75	67	71	Y
15	M	13.25	114	111	114	11	13	10	12	16	12	9	12	13	12	12	110	12.00	39	45	42	44	Y
16	M	12.92	115	105	112	11	13	14	12	13	11	12	10	12	14	6	115	12.60	40	62	65	64	Y

17	F	12.67	109	117	114	11	13	9	11	14		12	12	13	14	11	106	12.20	37	115	122	119	Y
18	M	12.58	107	108	108	12	12	10	11	11	8	9	13	10	11	13	99	12.30	38	52	32	42	Y
19	F	12.67	105	111	108	11	9	10	12	12	12	10	12	11	13	12	106	12.80	38	75	45	60	Y
20	F	13.25	88	104	95	8	8	9	8	8	10	8	15	10	10	10	105	12.30	40	192	162	177	Y
21	F	12.92	108	109	109	11	10	10	12	14	8	11	12	8	15	11	92	12.20	37	120	97	109	Y
22	F	13.08	92	95	92	9	8	10	8	9	9	7	9	9	8	14	104	12.60	40	142	100	121	N
23	M	13.75	97	92	94	11	8	10	10	9	13	10	11	10	6	8	105	12.60	39	70	62	66	Y
24	M	13.25	96	92	93	10	8	10	10	9	11	9	11	10	9	6	99	12.10	40	45	47	46	Y
25	M	12.92	122	118	123	14	14	12	14	14	11	15	14	13	12	9	113	12.80	39	107	122	115	N
26	M	12.67	101	101	101	10	12	9	10	10	10	14	4	10	11	12	119	11.90	35	47	45	46	Y
27	F	12.58	113	128	122	14	14	8	14	11	13	14	11	18	13	13	112	12.70	40	82	65	74	Y
28	M	12.67	130	124	130	14	15	15	14	16	12	15	13	14	14	11	130	12.50	40	75	52	64	M
29	M	12.75															113	12.70	38	87	85	86	Y
30	M	13.16	101	109	105	8	11	13	10	9	9	17	8	12	10	10	123	12.10	40	90	50	70	Y
31	F	13.08	118	132	128	11	15	13	16	10	14	11	11	19	19	13	130	12.80	40	35	25	30	Y
32	M	13.08	117	98	109	11	12	13	13	15	14	9	10	11	12	7	114	12.00	39	130	110	120	Y
33	M	12.50	136	131	138	16	17	18	13	14	16	14	11	15	15	17	119	12.50	40	72	55	64	Y
34	M	12.75	131	129	133	14	17	15	14	15	10	12	11	16	17	14	114	11.80	35	75	65	70	Y
35	M	12.58	141	124	137	15	18	16	15	18	16	11	14	17	13	12	118	13.00	40	102	95	99	N
36	M	12.75	97	104	100	9	10	12	9	8	12	10	10	14	11	8	118	12.00	39	42	47	45	Y
37	F	12.25	112	111	112	10	13	12	12	13	11	10	9	12	12	15	117	12.60	40	137	75	106	Y
38	M	12.83	111	130	122	12	12	12	13	10	10	14	13	19	16	9	130	11.90	37	30	30	30	Y
39	M	13.00	109	132	123	11	12	13	12	10	9	13	17	17	15	11	120	12.30	40	82	90	86	M
40	M	13.16	120	118	122	13	11	17	11	15	7	15	11	15	13	9	120	12.30	39	45	125	85	M
41	M	12.33	117	114	118	12	16	14	12	10	10	15	12	13	10	10	122	13.00	40	65	100	83	Y
42	M	12.33	122	101	113	12	12	12	11	10	11	11	11	11	9	9	107	12.80	39	87	85	86	Y
43	F	12.75	103	101	102	10	12	10	11	11	8	7	9	10	12	13	109	11.80	38	90	70	80	N
44	M	12.83	108	124	118	12	11	12	11	11	14	10	12	17	14	14	127	13.00	40	50	55	53	Y
45	M	12.58	111	115	114	12	13	10	13	11	11	12	10	14	13	12	130	12.30	40	27	37	32	Y
46	F	13.00	100	115	107	10	10	11	9	10	7	10	8	15	14	14	113	12.70	40	57	100	79	Y
47	M	12.50	114	108	112	12	12	16	11	11	7	9	10	12	13	12	107	11.90	40	85	87	86	Y
48	F	13.25	95	95	94	9	10	10	8	9	12	8	6	12	11	10	107	12.10	37	120	67	94	N
49	F	13.08	112	124	120	9	12	13	12	14	15	10	13	14	11	19	107	12.70	39	72	60	66	Y
50	F	13.00	105	106	105	9	12	10	11	12	10	10	10	11	10	14	112	12.20	36	42	35	39	Y
51	F	12.42	115	131	126	12	13	10	12	16	16	14	15	11	15	17	113	12.60	40	77	65	71	Y

52	F	12.50	102	115	109	9	12	10	10	11	14	14	11	11	13	12	124	11.90	40	42	47	45	N
53	F	12.42	122	115	121	12	14	18	11	13	15	11	13	12	11	14	113	12.10	39	145	177	161	N
54	F	12.33	109	117	114	11	12	14	9	12	7	10	13	16	12	11	118	12.30	40	47	52	50	Y
55	F	12.83	122	115	121	12	16	12	11	17	11	14	12	13	11	11	123	12.70	38	147	137	142	N
56	M	13.00	112	105	109	12	12	13	12	11	8	11	10	13	10	10	112	12.30	38	37	22	30	Y
57	M	13.57	123	105	117	13	15	14	14	13	14	10	12	13	10	9	118	12.40	39	72	65	69	N
58	M	13.00	119	126	125	12	12	17	13	12	11	15	14	16	11	12	121	12.70	40	70	32	51	N
59	M	12.58	123	105	117	14	14	16	13	12	13	10	8	14	13	9	126	12.50	39	75	125	100	Y
60	M	12.75	111	132	123	12	13	9	13	12	12	12	16	18	15	12	133	12.30	36	65	42	54	Y
61	M	13.00	105	117	111	11	12	11	9	11	12	11	11	17	14	9	127	12.30	38	52	52	52	Y
62	M	13.25	111	133	124	11	14	11	11	12	10	13	15	17	17	12	130	12.30	40	75	45	60	Y
63	F	13.25	122	118	123	12	14	12	13	17	7	10	12	14	13	14	107	12.10	39	100	90	95	Y
64	M	12.75	107	120	117	11	9	14	11	11	12	14	13	14	15	11	111	12.60	38	55	75	65	Y
65	M	13.25	113	126	121	10	12	14	12	13	14	13	13	19	13	10	113	12.70	39	95	87	91	Y
66	M	12.83	100	111	105	10	10	10	9	11	8	7	11	16	12	12	109	10.50	18	65	57	61	N
67	F	13.16	82	92	86	10	6	9	4	7	4	7	10	11	7	10	93	8.30	5	152	272	212	Y
68	F	13.08	92	93	92	9	11	6	8	10	5	11	9	11	12	3	112	7.70	10	85	72	79	Y
69	F	13.58	85	112	97	6	8	6	10	8	7	9	10	13	15	12	97	9.00	26	197	175	186	Y
70	F	12.50															107	9.30	28	102	97	100	Y
71	F	12.42	97	101	99	9	11	9	10	9	7	10	11	13	8	9	104	10.30	25	107	95	101	Y
72	F	13.08	81	106	92	6	8	8	6	7		10	11	14	10	10	101	10.00	29	117	155	136	Y
73	F	13.00	88	96	91	8	8	10	6	9	7	8	11	10	8	11	101	9.10	27	137	105	121	Y
74	F	12.33	91	93	91	9	8	9	7	10	5	11	9	9	9	8	107	8.60	24	125	100	113	Y
75	F	12.67	100	109	104	10	11	10	8	11	11	10	10	12	11	14	118	9.40	23	83	140	112	Y
76	M	13.00	91	101	95	9	10	6	9	9	6	10	16	9	10	6	109	9.80	28	52	42	47	N
77	M	12.92	80	105	91	6	5	9	7	7	9	11	10	12	11	10	110	9.30	29	62	55	59	N
78	F	13.00	107	117	112	10	11	11	11	12	8	13	11	11	17	10	127	10.90	29	102	65	84	Y
79	F	12.92	95	101	97	8	8	12	11	7		11	13	12	8	7	101	10.40	26	50	57	54	Y
80	F	12.92	92	104	97	9	9	10	8	8	7	7	13	14	13	6	100	9.60	27	115	105	110	Y
81	M	13.16	88	90	88	6	8	5	10	12	7	6	9	11	10	7	95	9.50	28	600	295	448	M
82	M	13.75	98	108	102	6	13	10	9	11	7	7	11	13	12	13	95	9.60	25	137	125	131	Y
83	F	13.33	80	90	84	9	7	5	5	8		10	10	8		6	95	8.30	16	122	125	124	Y
84	F	13.16	95	108	101	8	10	8	10	10	11	13	9	14	9	11	128	9.40	29	125	112	119	Y
85	M	13.83	81	92	85	8	5	10	4	8	10	11	8	8	11	7	91	7.90	19	130	122	126	Y
86	M	12.58	106	114	110	11	8	14	10	12	10	9	14	11	14	12	111	9.30	19	97	102	100	Y

87	M	12.83	81	109	93	9	8	3	6	9	8	11	12	11	12	11	101	8.80	23	125	97	111	Y
88	M	13.25	88	105	96	9	7	9	7	9	9	11	10	12	14	7	102	8.80	28	70	75	73	Y
89	M	12.83	106	121	114	11	12	12	10	10	10	14	11	13	16	11	104	8.30	18	60	45	53	Y
90	M	13.00	94	104	98	8	9	11	8	9	9	9	10	15	12	7	113	9.40	31	95	92	94	Y
91	M	13.33	97	118	107	11	10	10	8	9	9	13	13	12	14	11	103	9.00	32	70	127	99	Y
92	F	12.92	92	91	91	6	8	9	9	12	9	11	7	10	9	7	113	9.80	37	90	80	85	N
93	F	12.58	100	105	102	10	11	8	10	11	8	9	9	14	10	12	111	9.90	30	60	57	59	Y
94	M	12.75	114	117	118	13	10	15	11	13	12	15	11	12	15	9	119	9.80	36	145	62	104	Y
95	M	13.42	101	118	109	9	10	14	10	8	7	9	13	15	17	11	105	10.10	37	112	105	109	Y
96	M	13.00	114	118	118	11	11	12	11	17		11	14	13	15	10	109	10.30	35	165	107	136	Y
97	F	12.75	88	88	87	9	7	8	8	9	6	7	8	7	7	13	101	9.30	31	95	82	89	N
98	M	13.16	122	123	125	14	12	13	19	10	1	15	11	14	14	12	128	11.10	32	100	87	94	Y
99	M	13.25	90	95	91	7	8	9	8	10	10	9	7	10	11	10	101	10.20	36	185	142	164	Y
100	M	13.25	92	93	92	10	7	11	8	8		5	9	12	12	10	96	9.10	35	85	40	63	N
101	M	12.42															90	9.30	34	505	290	398	N
102	M	13.08	98	106	102	10	9	11	10	9	8	9	14	13	8	11	115	10.80	31	27	32	30	Y
103	M	13.08	111	112	112	10	12	15	10	12	15	11	9	12	17	10	116	10.80	39	92	70	81	Y
104	M	13.25	85	81	81	7	8	7	8	8	4	9	8	8	7	4	97	9.30	30	92	130	111	Y
105	M	13.67	90	90	89	7	7	11	7	10	7	9	8	10	7	9	93	9.90	36	80	95	88	Y
106	F	13.92	92	104	92	7	9	9	8	11	8	11	8	11	17	6	102	11.90	35	105	132	119	Y
107	M	13.08															100	10.50	33	67	62	65	Y
108	F	12.92	96	96	96	6	11	10	10	10	10	10	9	9	12	8	103	9.50	36	170	190	180	Y
109	F	12.92	100	92	96	11	13	6	10	10	6	10	4	10	13	8	109	10.10	32	185	132	159	Y
110	F	12.42	105	101	102	10	12	10	10	12	9	11	6	11	14	9	115	10.30	39	145	132	139	Y
111	M	12.42	105	102	103	9	8	10	8	9	10	11	9	13	8	11	95	9.90	33	65	37	51	Y
112	M	13.25	81	102	90	6	8	8	6	7	8	9	11	10	12	10	109	10.70	30	95	90	93	Y
113	M	13.16	114	106	112	12	12	15	11	12	11	13	8	14	8	12	114	11.80	32	15	30	23	N
114	F	12.75	106	115	111	10	10	13	10	12	9	13	15	10	12	11	107	11.40	31	150	147	149	Y
115	F	12.25	96	114	104	9	11	7	11	9	10	14	9	13	12	12	124	10.80	38	40	45	43	N
116	F	12.42	127	101	117	13	16	14	11	18	10	11	9	13	7	11	109	11.90	30	145	127	136	Y
117	M	13.25	115	86	101	12	12	14	12	13	10	9	6	10	10	5	104	11.70	38	67	95	81	Y
118	F		98	123	110	9	9	10	10	11	9	9	9	17	14	17	116		40	52	50	51	Y
119	F		117	135	128	13	13	12	13	13	9	15	12	15	19	14	118		40	110	67	89	N
120	M	12.92	112	120	118	11	11	15	12	11	11	14	11	14	15	10	111	11.10	40	120	132	126	Y
121	F	12.67	106	108	107	11	13	10	10	11	11	11	13	10	10	12	93		36	672	345	509	N

122	M	12.75	103	109	106	10	9	14	10	10	8	12	7	15	13	10	112	11.50	36	62	42	52	Y
123	M		127	125	127	12	13	17	12	16	9	13	11	17	13	13	104		38	42	57	50	Y
124	F	13.08	101	109	105	9	12	10	12	8	8	9	13	11	14	10	116	11.90	24	267	230	249	Y
125	M	13.00	106	101	103	10	12	8	13	12	8	18	10	9	10	4	116	11.50	29	182	17	100	N
126	M	13.25	100	101	100	11	8	11	9	11	11	13	6	16	12	4	128	11.60	37	75	22	49	Y
127	M	12.83	111			12	13	10	11	13	9	12	9				109	11.40	39	62	52	57	Y
128	M	13.08	113	91	102	12	12	10	13	14	9	11	5	10	10	8	98	11.50	39	70	55	63	Y
129	M	13.16	90	98	92	11	10	6	7	8	9	10	11	9	10	9	102	11.80	38	80	35	58	Y
130	F	12.75	101	112	106	10	11	12	9	9	11	11	11	14	13	10	107	11.10	39	145	195	170	Y
131	F	12.67	101	102	101	10	11	12	10	8	9	7	10	11	11	13	110	11.60	37	147	130	139	Y
132	F	12.83	88	112	100	9	8	10	7	7	11	10	13	15	12	9	107	11.30	36	137	112	125	Y
133	M	12.83	87	74	80	8	8	9	7	8	9	5	9	7	3	7	100	10.90	36	85	60	73	Y
134	F	12.92	119	95	109	11	15	14	11	15	11	9	8	10	10	10	103	11.80	39	105	85	95	Y
135	F	13.00	109	108	109	11	10	15	10	12	9	9	11	14	15	7	113	11.70	35	172	245	209	Y
136	F	13.08	95	95	94	9	8	10	10	9	13	7	7	12	9	12	115	11.90	37	107	97	102	Y
137	M	12.83	105	112	109	12	10	8	11	13	12	9	9	16	16	9	112	11.70	35	82	60	71	Y
138	M	12.75	98	102	100	10	11	9	9	10	16	10	10	12	10	10	116	11.60	40	40	85	63	Y
139	M	13.00	111	115	114	11	13	13	9	13	15	11	13	16	14	7	121	11.80	40	60	57	59	M
140	F	13.33	91	100	94	7	11	8	9	8	13	13	8	12	10	7	90	11.90	40	182	127	155	Y
141	F	12.75	107	109	109	12	11	10	11	12	8	10	11	11	12	13	107	10.80	35	130	130	130	Y
142	M	12.83	109	100	105	12	13	9	12	12	8	10	11	13	12	4	96	11.00	28	112	70	91	Y
143	M	13.08	98	108	102	10	10	10	9	10	10	13	9	10	14	10	92	11.90	39	107	80	94	Y
144	F	13.08	98	100	99	12	9	5	11	12	9	11	13	9	8	9	113	11.90	37	87	60	74	Y
145	M	13.00															106	11.40	30	55	125	90	Y
146	M	12.92	105	91	98	10	10	13	11	10	10	10	6	10	10	8	106	11.80	39	57	42	50	Y
147	F	13.25															111	11.30	27	82	92	87	Y
148	F	13.25	95	120	106	9	8	9	8	12	8	11	12	12	15	14	107	11.70	34	67	42	55	Y
149	F	13.25	106	124	116	9	10	15	10	11	10	11	16	11	13	16	105	11.30	36	145	92	119	Y
150	F	12.75	108	92	101	11	10	12	11	13	9	8	9	10	6	12	98	11.30	36	117	25	71	Y
151	M	12.83	102	124	113	12	10	8	9	13	7	12	13	15	14	13	106	12.30	34	107	62	85	Y
152	M	12.83															103		32	135	82	109	Y
153	M	12.92	100	123	111	11	11	8	9	11	5	12	15	11	15	13	101	11.80	32	35	17	26	Y
154	M	12.67	92	91	91	11	10	7	9	7	11	11	11	6	10	6	103	11.80		130	102	116	Y
155	M	13.08	106	128	118	11	10	9	11	14	8	15	15	13	14	12	104	12.30	32	50	52	51	Y

APPENDIX E

Table E-1: Correlations between IT and WISC-R IQ measures for the total sample and each subsample.

	All subjects (N = 155)	Normals (n = 65)	SRDs (n = 24)	Controls (n = 24)
FSIQ	-.15	-.14	-.38	.09
VIQ	-.15	-.12	-.28	-.14
PIQ	-.12	-.14	-.41 *	.30
INF	-.19	-.18	-.42 *	-.17
SIMIL	-.06	-.04	-.20	-.02
ARITH	-.18	-.05	-.38	-.36
VOCAB	-.14	-.16	-.04	-.18
COMP	-.02	-.06	-.19	.05
DIG SP	-.06	-.06	-.23	.17
PIC COMP	-.08	-.02	-.54 **	.46
PIC ARR	-.06	-.26	-.37	-.29
BL DES	-.17	-.07	-.10	.26
OBJ ASS	-.04	-.03	-.20	.19
CODING	-.04	-.12	-.03	.21

* $p < .05$, ** $p < .01$, two-tailed

Table E-2: Correlations between IT and WISC-R IQ measures for users and non-users of apparent motion cues in the total and normal sample.

	TOTAL SAMPLE (N = 155)		NORMAL READERS (n = 65)	
	Users (n = 127)	Non-users (n = 28)	Users (n = 51)	Non-users (n = 14)
FSIQ	-.27 *	-.11	-.07	-.12
VIQ	-.27 *	-.11	-.02	-.21
PIQ	-.20 *	-.07	-.11	.04
INF	-.34 **	-.11	-.16	-.08
SIMIL	-.16	-.02	-.06	-.17
ARITH	-.14	-.31	-.15	-.42
VOCAB	-.30 **	-.03	-.29	-.14
COMP	-.14	.06	.22	-.04
DIG SP	-.18	.01	-.09	.07
PIC COM	-.20	-.04	-.04	.20
PIC ARR	-.05	-.12	.03	-.35
BL DES	-.27 *	-.13	-.29	.03
OBJ ASS	-.01	-.06	-.06	.08
CODING	-.13	.08	.01	.32

* $p < .05$, ** $p < .01$, two-tailed